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Using machine learning to predict artistic styles: an analysis of trends and the research agenda

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Abstract
In the field of art, machine learning models have been used to predict artistic styles in paintings. The foregoing is somewhat advantageous for analysts, as these tools can provide more valuable results and help reduce bias in the results and conclusions provided. Therefore, the objective of this research was to examine research trends in the use of machine learning to predict artistic styles from a bibliometric review based on the PRISMA methodology. From the search equations, 268 documents were found, out of which, following the application of inclusion and exclusion criteria, 128 documents were analyzed. Through quantitative analysis, a growing research interest in the subject is evident, progressing from user perception approaches to the utilization of tools like deep learning for art studies. Among the main results, it is possible to identify that one of the most used techniques in the field has been neural networks for pattern recognition. Also, a large part of the research focuses on the use of design software for image creation and manipulation. Finally, it is found that the number of studies focused on contemporary modern art is still limited, this is due to the fact that a large part of the investigations has focused on historical artistic styles.

Keywords Machine learning · Deep learning · Artistic styles · Color · Image analysis · PRISMA

Abbreviations

AI	Artificial intelligence
CGANs	Conditional generative adversarial networks
CNN	Convolutional neural networks
GAN	Generative adversarial networks
IEEE	Institute of Electrical and Electronics Engineers
IML	Interactive machine learning model
IUI	International conference on intelligent user interfaces
ML	Machine learning
NLMC	Non-linear matrix completion
NLP	Natural language processing
PRISMA-2020	Preferred reporting items for systematic reviews and meta-analyses 2020

Extended author information available on the last page of the article

QArt-Learn	Categorizing paintings in art styles based on qualitative color descriptors, quantitative global features, and machine learning
SOM	Self-organizing map
SPIE	The international society for optical engineering
VR	Virtual reality
XRF	X-ray fluorescence spectra

1 Introduction

Machine learning models designed to forecast artistic styles in paintings leverage advanced algorithms capable of acquiring highly abstract and hierarchical representations from extensive datasets encompassing both historical and contemporary artistic images. These models prominently utilize deep neural network architectures, including convolutional neural networks (CNNs) and generative adversarial networks (GANs), to discern significant visual features within paintings, unveiling distinct stylistic patterns. By embracing machine learning techniques, these models effectively surmount the constraints of traditional methods, yielding results that are both more precise and reliable (Mao 2022; Wenjing and Cai 2023).

Prior research has underscored the efficacy of these models across diverse domains within the social and human sciences, as well as the arts, particularly in the assessment of artistic designs through artificial intelligence and machine learning methodologies (Wenjing and Cai 2023). Noteworthy applications include the utilization of machine learning algorithms to identify and visualize color pigments in cultural heritage artworks (Chen et al. 2022). Additionally, studies have delved into the application of artificial intelligence for safeguarding Dunhuang cultural heritage, involving the creation of a comprehensive dataset in this domain (Yu et al. 2022). Other endeavors have explored the development of a catalog raisonné using artificial intelligence and machine learning (Dobbs et al. 2022).

The integration of machine learning models into the prediction of artistic styles in paintings has emerged as a topic of paramount significance, situated within the interdisciplinary realms of computer vision and artificial intelligence as applied to the analysis of visual art. Within this broader context, the significance of these models in intelligently analyzing art becomes apparent, suggesting that the incorporation of virtual reality and machine learning technologies holds the potential to substantially enhance educational processes within the artistic domain (Mao 2022). Furthermore, research underscores the utility of machine learning models in predicting the evolution of damage in panel paintings, offering a valuable contribution to the preservation of artistic heritage (Califano et al. 2022).

In a broader context, Lürig et al. (2021) underscore the potential of computer vision and machine learning across disciplines like ecology and evolutionary biology, where predictive models have propelled significant advances in phenomics. They posit that applying machine learning models to the analysis of artistic styles in paintings holds the promise of deepening our understanding of art history, the influence of masters on their students, and the evolution of trends over time. This aligns with the work of Sanhudo et al. (2021), who utilized machine learning techniques to classify intricate work activities in the construction sector.

Research on the utilization of machine learning models for predicting artistic styles in paintings reveals certain gaps, warranting bibliometric analysis to address and scrutinize the current state of scientific literature in this domain. A primary gap lies in the

necessity to explore and advance machine learning techniques capable of capturing the intricate complexity and diversity inherent in both historical and contemporary artistic styles found in paintings. While existing approaches exist, many tend to focus on specific methodologies or the classification of fragments rather than the comprehensive prediction of the artistic style of an entire work, as noted by Cascone et al. (2023).

Furthermore, there is a need for additional research on the interpretation and explanation of features learned by machine learning models employed for this task. This would foster a deeper understanding of how these models make decisions, ultimately enhancing their reliability and applicability in practical contexts (Li and Zhang 2022). Similarly, despite considerable progress in applying artificial intelligence and machine learning across various fields, such as optimizing industrial operations (Allahloh et al. 2023) and art design (Xu and Nazir 2022), it is imperative to specifically focus on analyzing techniques and approaches applied to predicting artistic styles in paintings. This targeted exploration aims to identify the most promising trends and approaches in this emerging field.

The development of a review study, according to the scientific literature, will allow the compilation, analysis and synthesis of information from different scientific sources, which will provide a holistic vision of the current state of research in deep learning models for predicting artistic styles in paintings. By identifying the most outstanding advances, limitations, and approaches, this literature review will contribute to the development and improvement of new approaches in the field and promote future research in critical areas that require further attention and development (Allahloh et al. 2023; Cascone et al. 2023; Xu and Nazir 2022). In this sense, the aim of this research is to examine the research trends in the use of machine learning for artistic style prediction, with the aim of providing a research agenda for future research. In addition, the following research questions are posed and its motivation:

RQ1 What are the years in which there has been more interest in using machine learning to predict artistic styles? This question arises with the aim of; Identifying the temporal trends in the interest and application of machine learning in predicting artistic styles by examining the years where this interest peaked.

RQ2 What is the growth in the number of scientific articles on the use of machine learning for predicting artistic styles? This question arises with the aim of; Understanding the growth pattern and trajectory of scientific articles focusing on the utilization of machine learning for predicting artistic styles over time.

RQ3 What are the main research references on the use of machine learning for predicting artistic styles? This question arises with the aim of; Determining the primary and influential research works in the domain of machine learning used for predicting artistic styles, emphasizing key references that have significantly impacted this field.

RQ4 What is the thematic evolution derived from the scientific production on the use of machine learning for predicting artistic styles? This question arises with the aim of; Analyzing the thematic evolution derived from the collective body of scientific production concerning the use of machine learning for predicting artistic styles, tracking the changes in predominant themes over time.

RQ5 What are the main thematic clusters on the use of machine learning for predicting artistic styles? This question arises with the aim of; Identifying and delineating the main thematic clusters or groupings within the research landscape of machine learning applications for predicting artistic styles, highlighting distinct areas of focus or concentration.

RQ6 What are the growing and emerging keywords in the research field of the use of machine learning for the prediction of artistic styles? This question arises with the aim of; Uncovering the emerging and growing keywords within the research field concerning the utilization of machine learning for the prediction of artistic styles, indicating developing areas or novel aspects garnering increased attention.

RQ7 What issues are positioned as protagonists for the design of a research agenda on the use of machine learning for predicting artistic style? This question arises with the aim of; Exploring and determining the key issues that play central roles in shaping the design and formation of a comprehensive research agenda regarding the utilization of machine learning for predicting artistic styles.

2 Literature review

Initially, among the works developed between the 2000 and 2010 s that related digital technology to art were research studies focused on assessing the aesthetic visual quality of a specific type of visual medium, specifically digital images of paintings. For example, Li and Chen (2009) tackled this challenge as a machine learning problem, aiming to evaluate the aesthetic quality of paintings based on their visual content. They designed a set of methods to extract features representing both global and local char-acteristics of a painting. In another study by Tzeng et al. (2005), the authors introduced a new approach to the volume classification problem that combined machine learning and a painting metaphor to allow more sophisticated classification in an intuitive manner. They trained a system to classify the entire painted volume and represent visual information immediately as the painting progressed in a much larger dimensional space without explicitly specifying the mapping for each dimension used.

One of the significant contributions to research on Machine Learning in painting was a review work where the authors examined whether machine learning and image analysis tools could be used to assist art experts in authenticating unknown or disputed paintings. The authors reexamined some recently successful experiments, showing that variations in image clarity in experimental datasets correlated with authenticity and might have acted as a confounding factor, artificially improving the results (Polatkan et al. 2009). In a different approachFails and Olsen (2003a, b, c) proposed a tool for creating new camera-based interfaces using a simple painting metaphor. They utilized transparent layers to present all necessary information to the designer, adapting traditional machine learning algorithms to suit the rapid response time required by an interactive design tool. In 2005, Yelizaveta et al. (2005) presented an automated approach to analyzing and representing artistic color concepts, such as color temperature, color palette, and color contrasts in the realm of paintings. They achieved this by extracting homogeneous color/texture regions from

paintings and employing image processing and machine learning techniques to characterize regions in terms of artistic color concepts.

Moving into the 2010s, deep neural networks began to gain prominence. One of the most relevant works involved generating realistic images using deep neural networks. Liu et al. (2018) focused on investigating the sketch-to-image synthesis problem using conditional generative adversarial networks (cGANs), proposing a model called Auto-Painter that could automatically generate compatible colors given a sketch. Another intriguing work revolved around nonlinear matrix completion (NLMC), ex-tending classical techniques of linear matrix completion to the nonlinear case for recognizing emotions in abstract paintings (Alameda-Pineda et al. 2016). Another interesting contribution was made by Falomir et al. (2018), who presented the QArt-Learn approach for categorizing painting styles based on qualitative color descriptors (QCD), color similarity (SimQCD), and quantitative global features (such as average brightness, hue, saturation, and contrast of luminosity and brightness) to understand the characteristics of Baroque, Impressionist, and Post-Impressionist paintings.

There was also a study that aimed to automatically identify paintings by Vincent van Gogh using a Convolutional Neural Network that extracted discriminative visual patterns directly from images, coupled with a machine learning classifier and a fusion method in the final decision-making process (Folego et al. 2016). Another related interesting work was by Belhi et al. (2018), addressing the challenge of automatically classifying and annotating cultural heritage artifacts using their visual characteristics and available metadata. They presented a multimodal classification approach for cultural heritage artifacts based on a multitask neural network, where a convolutional neural network (CNN) was designed for visual feature learning and a regular neural network for textual feature learning.

For this same decade, specifically in 2019, an article was published that presented the state of the art in artificial intelligence. The article initially defined AI and its relationship with machine learning and deep learning, followed by a brief timeline of AI evaluation, advantages, and challenges in the current world. It then discussed the three fundamental problem-solving techniques: knowledge and reasoning, neural networks, and natural language processing (NLP) (Mondal 2019). However, the author generalized this state of the art and did not delve specifically and deeply into its relation with art, particularly painting.

An intriguing work, despite not having the highest number of citations and published in 2011, focused on an approach to the automatic classification of paintings by artistic genre. The authors classified six genres: realism, impressionism, cubism, fauvism, pointillism, and naive art, demonstrating how automated classification is useful for processing large databases in institutions like museums, and could also find applications in contemporary platforms, including mobile applications (Čuljak et al. 2011). This not only aids in cataloging historical artworks but also sets the stage for how technology can make art more accessible in the contemporary digital era.

Furthermore, in a more in-depth automatic analysis presented by Van Der Maaten and Erdmann (2015), an algorithm capable of conducting canvas-level analysis was introduced. This algorithm not only provided insights into individual threads in the canvas X-ray but also demonstrated the potential for combining traditional art analysis with modern computational techniques. The authors applied this method to a small collection of paintings apparently by Nicholas Poussin and a small collection of paintings by Vincent van Gogh, emphasizing the enduring relevance of historical artworks in the contemporary analytical landscape.

Moving into the 2020s, one of the articles that had a significant impact presented the affective experience triggered by visual artworks. The researchers asked annotators to indicate

the dominant emotion they felt for a specific image and, more importantly, to provide a well-founded verbal ex-planation for their emotion. They focused on visual art (e.g., paintings, artistic photographs), demon-strating a series of captioning systems capable of expressing and explaining emotions from visual stimuli (Achlioptas et al. 2021). Another interesting contribution in this decade for painting using machine learning was an algorithm designed to automatically generate reliability evaluations for facial action units (smile, eyebrows, etc.) in European portraits in large historical databases. The authors suggested that increased reliability demonstrations are associated with a higher standard of living (Safra et al. 2020). In 2020, the Self-Organizing Map (SOM), an unsupervised machine learning algorithm based on neural networks, was applied to introduce a novel approach to spectral image data analysis. This method automatically reduced hundreds of thousands of X-ray fluorescence spectra into a handful of distinct groups sharing similar spectra (Kogou et al. 2020).

Moreover, another work conducted in 2020 proposed a method to integrate an artistic style into brushstrokes and the painting process through the collaboration of robotic painting with a human artist. They collected brushstrokes and manual brush movement samples from an artist, then trained a gen-erative model to generate brushstrokes belonging to the artist's style. They subsequently adjusted a stroke-based representation model to work with their robotic painting setup (Bidgoli et al. 2020). In 2021, some authors proposed using a convolutional graph network and artistic comments instead of paint color to classify the type, school, time period, and author of paintings by implementing natural language processing (NLP) techniques (Zhao et al. 2021). Later, in a work by Tian and Nan (2022), published in 2022, they proposed a multitask convolutional neural network model for the emotion and rating of artworks. They created an artwork appreciation dataset consisting of fifty Chinese paintings and fifty Western oil paintings, recruiting twenty subjects to rate the art appreciation of a hundred artworks in the dataset, encompassing both aesthetic evaluation and emotion evaluation of the painting. Subsequently, using the artwork appreciation dataset, they proposed a convolutional neural network model based on AlexNet to utilize the powerful feature extraction and classification capabilities of neural networks to complete the appreciation of artworks.

Finally, among the most recent works published in the last year, there is the contribution of Spee et al. (2023), who used Machine Learning to probe complex associations between 17 subjective artistic attributes and judgments of creativity in a wide range of artworks. Random Forests regression models applied represented 30% of the variability in judgments of creativity from the set of artistic attributes, revealing that symbolism, emotionality, and imagination are the main attributes influencing judgments about creativity. Another interesting contribution was made by Mengyao and Yu (2023), who conducted a trend analysis in product art design, primarily focusing on industrial product design using machine learning. Throughout time, various review articles have been conducted, focusing on the advancement of artificial intelligence, emotion review, or, like the latter, on the use of artificial intelligence spe-cifically for industrial product design, but they do not focus on predicting artistic styles. A few of the articles included in this literature review, comprising the most cited articles from the 2000 to 2010 s and the most recent ones in the 2020s, are summarized below, as depicted in Table 1.

3 Materials and methods

In order to achieve the objective of the research, a bibliometric analysis is proposed. The methodology followed in this bibliometrics adheres to the guidelines established by the PRISMA 2020 declaration (Page et al. 2021) for conducting literature reviews,

Table 1 Summary of the review of articles published on the topic of machine learning and artistic painting

Title	Authors	Year	Focus
Aesthetic visual quality assessment of paintings	Li and Chen	2009	Evaluating aesthetic quality of paintings based on visual content
An intelligent system approach to high-dimensional classification of volume data	Tzeng et al.	2005	Classifying volume data using machine learning and painting metaphors
A design tool for camera-based interaction	Fails and Olsen	2003	Creating camera-based interfaces with a painting metaphor
Analysis and retrieval of paintings using artistic color concepts	Yelizaveta et al.	2005	Analyzing color concepts in paintings using image processing and ML
Auto-painter: cartoon image generation from sketch by using conditional wasserstein generative adversarial networks	Liu et al.	2018	Generating images from sketches using conditional generative networks
Recognizing emotions from abstract paintings using non-linear matrix completion	Alameda-Pineda et al.	2016	Identifying emotions in abstract paintings using matrix completion
Categorizing paintings in art styles based on qualitative color descriptors, quantitative global features and machine learning (QArt-Learn)	Falomir et al.	2018	Categorizing paintings based on color descriptors and ML
Artificial intelligence: state of the art	Mondal	2019	Overview of AI and its relationship with machine learning and NLP
Leveraging known data for missing label prediction in cultural heritage context	Belhi et al.	2018	Automatic classification and annotation of cultural heritage artifacts
From impressionism to expressionism: automatically identifying van Gogh's paintings	Folego et al.	2016	Identifying van Gogh's paintings using CNN and machine learning
Classification of art paintings by genre	Čuljak et al.	2011	Automatically classifying paintings by artistic genre
Automatic thread-level canvas analysis: a machine-learning approach to analyzing the canvas of paintings	Van Der Maaten and Erdmann	2015	Analyzing canvas threads in paintings using machine learning
ArtEmis: affective language for visual art	Achlioptas et al.	2021	Explaining emotions in visual art through captioning systems
Detection of forgery in paintings using supervised learning	Safra et al.	2020	Detecting forgery in European portraits using supervised learning
A new approach to the interpretation of XRF spectral imaging data using neural networks	Kogou et al.	2020	Analyzing XRF spectral imaging data using neural networks
Artistic style in robotic painting; a machine learning approach to learning Brushstroke from human artists	Bidgoli et al.	2020	Integrating artistic style into robotic painting using machine learning
How to represent paintings: a painting classification using artistic comments	Zhao et al.	2021	Classifying paintings based on comments instead of color

Table 1 (continued)

Title	Authors	Year	Focus
A multitask convolutional neural network for artwork appreciation	Tian and Nan	2022	Multitask CNN for artwork appreciation and emotion evaluation
Machine learning revealed symbolism, emotionality, and imaginativeness as primary predictors of creativity evaluations of western art paintings	Spee et al.	2023	Investigating attributes influencing judgments about creativity in artworks
Intelligent product art design based on smart equipment and machine learning algorithm: practice effect and trend analysis	Mengyao and Yu	2023	Trend analysis in product art design using machine learning

thus focusing on the analysis of metadata, which allows obtaining a panoramic and comprehensive vision of the current state. from research on machine learning models applied to the prediction of artistic styles in the field of painting. The PRISMA method is one of the most recent and widely used for literature reviews, allowing greater specificity in establishing inclusion and exclusion criteria for research. This helps reduce bias in the selection and inclusion of documents in the research and literature review. Additionally, the recent update to the PRISMA statement better aligns with the quantitative and qualitative criteria generated for obtaining results, enabling the combination of results from multiple databases and subsequent selection and cleaning of results for analysis.

3.1 Eligibility criteria

In the context of bibliometrics on the use of machine learning models to predict artistic styles in paintings, the inclusion criteria are based on three fundamental aspects. First, the metadata of the title and abstract are considered as essential elements for the selection of the records. Second, articles containing a combination of the terms "machine learning" and terms beginning with "painting" are included. Finally, those documents related to the field of health are excluded.

This entails the inclusion of articles across various document types, encompassing scientific papers published in journals and conference proceedings indexed in each database. Additionally, articles in all languages are considered, with metadata uniformly translated into English within the databases. Furthermore, the chronological aspect is comprehensively addressed, incorporating articles from all years for which information is available, aligning with the established criteria. This inclusive approach ensures a comprehensive and linguistically standardized coverage of relevant literature across diverse document types and temporal contexts.

To carry out the bibliometrics, three phases of exclusion are established. In the first phase, all records with incorrect indexing are discarded. In the second phase, those documents are excluded that do not have access to the full text, but it is important to note that this restriction only applies to systematic literature reviews. Finally, in the third phase of exclusion, those records with incomplete indexing are eliminated, which guarantees the integrity and reliability of the data used in the bibliometric analysis.

3.2 Sources of information

The databases Scopus and Web of Science have been selected because of their relevance and importance as the main sources of scientific information today. Scopus and Web of Science offer a wide coverage of academic publications from different disciplines, which guarantees the inclusion of a large number of articles related to the research topic in question. In addition, they have been widely used in similar studies, which ensures a more accurate and consistent comparison with previous research (Pedraza-Navarro and Sánchez-Serrano 2022).

3.3 Search strategy

To carry out the bibliometric search in the two selected databases, two highly specialized search equations were developed, adapted to the previously defined inclusion criteria and

the specific characteristics of each database. For the Scopus database, the following search equation was used: (TITLE("machine learning" AND painting*) OR ABS ("machine learning" AND painting*)) AND NOT ALL (health). Meanwhile, for the Web of Science database, the search equation used was: (TI= ("machine learning" AND paintin*) OR AB = ("machine learning" AND paintin*)). These search strategies were designed with a third-person scientific approach to ensure accurate identification of relevant studies on machine learning models used to predict artistic styles in paintings. These equations were adjusted for each database based on the results they yielded, both in quantity and relevance to the researched topic. In the case of the Web of Science database, the use of the term 'paintin*' did not limit the results as much as the term 'painting*.

Furthermore, it is noteworthy that the search process was conducted in August 2023. This temporal consideration is particularly pertinent given the dynamic nature of the field. Subsequent literature searches beyond this date may yield a greater volume of information, reflecting the evolving landscape of research in the field.

3.4 Data management

In the development of bibliometrics on the use of machine learning models to predict artistic styles in paintings, Microsoft Excel® was used as a basic tool for extracting, storing and processing information from each database. data used in the study. Likewise, the free software VOSviewer® was used in combination with Microsoft Excel® to create graphical representations of the different bibliometric indicators obtained. This tool facilitated the visualization and analysis of the relationships between the bibliographic elements and provided a clear vision of the emerging patterns and trends in the scientific literature on the topic of interest (Orduña-Malea and Costas 2021). The use of Microsoft Excel® in this study was central to the comprehensive data management process, particularly in handling the vast amount of information extracted from each database. It played a pivotal role in data extraction, storage, and organization from the chosen scientific reports. The utilization of Microsoft Excel®, in combination with VOSviewer®, aided in data visualization and facilitated the creation of graphical representations of bibliometric indicators. These tools were crucial for the analysis, allowing us to observe emerging patterns and trends in the scientific literature on machine learning models applied to predicting artistic styles in painting.

3.5 Selection process

In accordance with the PRISMA 2020 statement, as stated in the work of (Page et al. 2021), it is essential to highlight whether an internal automatic classifier was used in the selection process and whether internal or external validation was performed, with the purpose of confirming:—Understand the risk associated with the possibility of losing relevant studies or their misclassification. In the present study on the use of machine learning models to predict artistic styles in paintings, an automation tool developed in Microsoft Excel® was used, which was created collaboratively by all the researchers involved in the study. Independently, the researchers used this tool in the inclusion and exclusion phases of the study to reduce the risk of losing relevant research or incorrect classifications when converging the results obtained.

The tool employed is identified as a metadata processing tool, operating not autonomously but in accordance with the instructions provided by the authors. The

tool's effectiveness is directly linked to the quality and comprehensiveness of the entered information, depending on the inputs provided to carry out its functions. In consideration of the established inclusion criteria, the tool has demonstrated its capability to incorporate texts in all languages and from all available years. Additionally, its versatility is highlighted as it encompasses various document types, including both journal articles and conference proceedings, provided they are appropriately indexed in the relevant databases.

3.6 Data collection process

Microsoft Excel® was used as an automated tool for the data collection process, facilitating the organization and systematization of the information extracted from each scientific report. The data collection process involved all the authors of this study, who acted as reviewers to validate the information extracted from the selected reports. It should be noted that the authors worked independently, thus ensuring impartiality and objectivity in data validation. In addition, a data confirmation process was carried out collectively among the authors until absolute convergence of the results obtained was reached. This ensured the consistency and precision of the data used in the bibliometric analysis.

3.7 Data elements

Comprehensive data searches were performed for all outcomes related to the research objective. This implied the design of specific search equations for each database, with the aim of identifying all relevant articles mentioning said models. However, those texts that presented missing or unclear information were excluded, since their inclusion could compromise the solid understanding of the knowledge base on the topic. In this way, the coherence and adequacy of the study with its purpose and scope were ensured. It should be mentioned that all additional variables, such as participant characteristics, intervention, and funding sources, were also rigorously sought and defined according to a third-person scientific perspective. This aimed to ensure an impartial and objective approach in collecting and defining variables beyond the primary focus. This perspective encompasses a neutral stance, avoiding subjective interpretations or biases that could influence the study's outcomes. The comprehensive data searches undertaken were designed to encompass all relevant outcomes aligned with the research objectives. This entailed crafting specific search equations tailored for each database to capture articles pertaining to the mentioned models. Articles lacking clarity or presenting incomplete information were excluded as their inclusion might have jeopardized a thorough understanding of the subject matter. This rigorous approach ensured the study's coherence and alignment with its intended purpose and scope.

3.8 Assessment of risk of bias in studies

In addition, it is necessary to specify the methods used to assess the risk of bias of the studies included in the analysis. For this purpose, it was considered crucial to detail the tools used, the number of reviewers involved in each stage of the process, and their degree of independence. Similarly, the use of an automated tool in the data collection process is highlighted, which in this specific case corresponds to Microsoft Excel®.

In accordance with the methodology adopted, all authors were involved in the data collection and the risk of bias was assessed in the same way. The use of the automated Microsoft Excel® tool guaranteed the uniformity and consistency of the process, which contributed to maintaining the quality and integrity of the results obtained. It should be noted that this tool provides a systematic and efficient approach to the analysis of the included studies, which strengthens the validity and reliability of the conclusions drawn from this bibliometric work.

3.9 Effect measures

The reporting of effect measures refers to the presentation of quantitative results that assess the impact or relationship between the variables studied (Page et al. 2021). These measures, such as risk ratio or mean difference, are commonly used in primary research to analyze the magnitude and statistical significance of the observed effects.

However, this review, which is based on secondary research sources, takes a different approach by not directly synthesizing the results of primary studies. Instead, the scientific landscape on the topic is analyzed by examining the number of publications and the number of citations related to the topic of interest. In addition, Microsoft Excel® is used to evaluate the temporality of the use of keywords in the publications, which provides a vision of the evolution of interest in the topic over time.

In addition, VOSviewer® is used to identify and visualize the existing nodes, allowing to determine the thematic association between the different studies. It is important to emphasize that although this research does not use traditional impact measures, its approach provides valuable information for understanding the evolution and relevance of the topic in the scientific field.

3.10 Methods of synthesis

In the context of this research on the use of machine learning models to predict artistic styles in paintings, different procedures were followed to decide which studies to include in the bibliometric synthesis. For this purpose, specific criteria described previously were applied. In addition, methods were adopted to prepare the data adequately for presentation and synthesis. With regard to the visualization of the results of the individual studies and their synthesis, tables and graphical representations were used to facilitate the understanding and analysis of the results, based on the bibliometric indicators presented in (Durieux and Gevenois 2010). These indicators were automatically applied, using Microsoft Excel®, to all the documents that passed the three stages of exclusion. This automated approach made it possible to efficiently analyze and quantify key aspects of scientific production related to the study of machine learning models for predicting artistic styles in paintings.

3.11 Assessment of reporting bias

In the context of a bibliometrics on the use of machine learning models to predict artistic styles in paintings, it is crucial to consider and assess the risk of bias derived from the lack of results in a synthesis, which may arise due to reporting biases. It is important to note that in the present study, there may be a bias towards certain synonyms found in thesauri such

as the IEEE. This bias may manifest itself in the inclusion criteria, search strategy, and data collection. In addition, by establishing exclusion criteria based on incomplete indexing of the texts, it is possible that valuable information for building knowledge about the subject in question is omitted. Therefore, care must be taken when interpreting and analyzing the results, considering the possible influence of these biases in the bibliometric synthesis.

3.12 Assessment of certainty

This section deals with the assessment of the certainty of the evidence for the results obtained. In contrast to primary studies, which assess certainty individually, this methodology focuses on assessing certainty in a general way, through the independent application of inclusion and exclusion criteria and the definition of bibliometric indicators. In addition, the reporting of possible biases identified in the methodological design is highlighted and the limitations of the study are mentioned during the discussion phase. Figure 1 presents the flowchart recommended by (Durieux and Gevenois 2010) to describe the methodological design.

Finally, of the 268 documents previously obtained between the two databases, after eliminating the duplicates and completing the three phases of exclusion, there is a total of 128 articles that will finally be analyzed in the present bibliometric analysis.

4 Results

The bibliometric analysis on the use of machine learning models to predict artistic styles in paintings has allowed us to analyze the volume of annual publications, as shown in Fig. 2, which has revealed a remarkable exponential growth in scientific production. related to this topic, with an impressive increase of 98.49%. This analysis has focused mainly on the years 2020, 2021 and 2022, which have been identified as the periods with the highest number of publications on the subject. These results show a clear upward trend in interest and research in the use of machine learning techniques to address the prediction of artistic styles in paintings, highlighting the potential and relevance of this area in the scientific field. Among the most recent publications, for the year 2023, is the work of Lc (2023), where the authors use visions of climate futures generated by machine learning (stable diffusion, half-trip, etc.) and potential climate adaptations from the use of ChatGPT in a creative space to reconstruct a modern analog scene of ancient cave painting. In addition, the research of (Mengyao and Yu 2023) analyzed the artistic design of smart home products based on machine learning and found that household appliances and lamps will affect the aesthetic feeling of the entire interior design. This addresses questions 1 and 2: What are the years in which there has been more interest in using machine learning to predict artistic styles? and What is the growth in the number of scientific articles on the use of machine learning for predicting artistic styles?

An analysis of the main research references is then presented, broken down by main authors, journals and countries. Regarding the former, as shown in Fig. 3, three groups of prominent authors have been identified. In the first place, there are those with remarkable scientific productivity and impact, among which only Fails JA stands out, with 354 citations for his main work, which, together with other authors, proposes an interactive machine learning model (IML). (IML) that allows users to train, classify/view, and correct images (Fails and Olsen 2003a). Second, there is a group of authors who stand out for

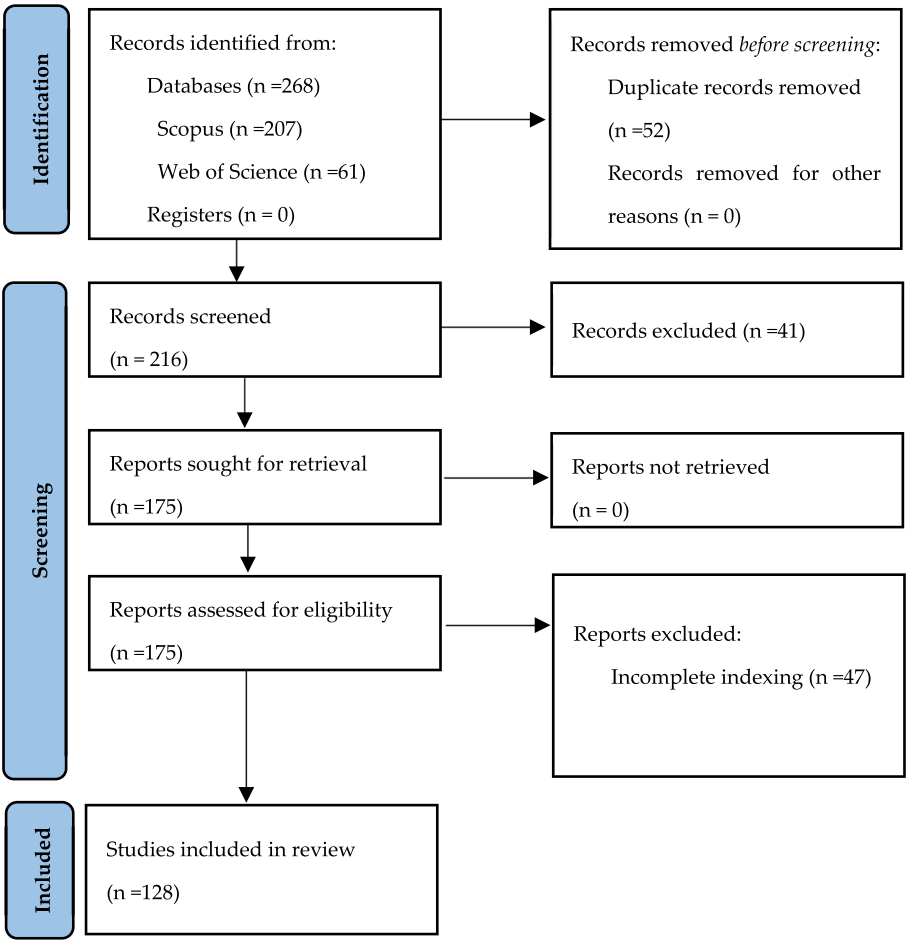

Fig. 1 PRISMA flow chart. Adapted from Scopus and Web of Science

their impact on the scientific community despite their low productivity, including Olsen; Li and Chen; and Tzeng, Lum, and Ma. Finally, a group of relevant authors is identified due to their high scientific productivity, although not necessarily due to their number of citations, Zhang X being one of the main references in this category. These results allow a better understanding of the dynamics and contributions of the different groups of authors in the field of deep learning applied to the analysis of artistic styles in paintings. This answers the third question regarding: What are the main research references on the use of machine learning for predicting artistic styles?

In the context of the analysis of the most important journals as part of the research references, two groups of prominent scientific journals were identified, as shown in Fig. 4. On the one hand, journals were found that stand out for their impact on the community, despite a low productivity in terms of publications, among which the "International Conference On Intelligent User Interfaces" and the "IEEE Journal on Select Topics in Signal Processing" stand out. On the other hand, a second group of reference journals was identified due to their high scientific productivity, although not necessarily due to their number of citations,

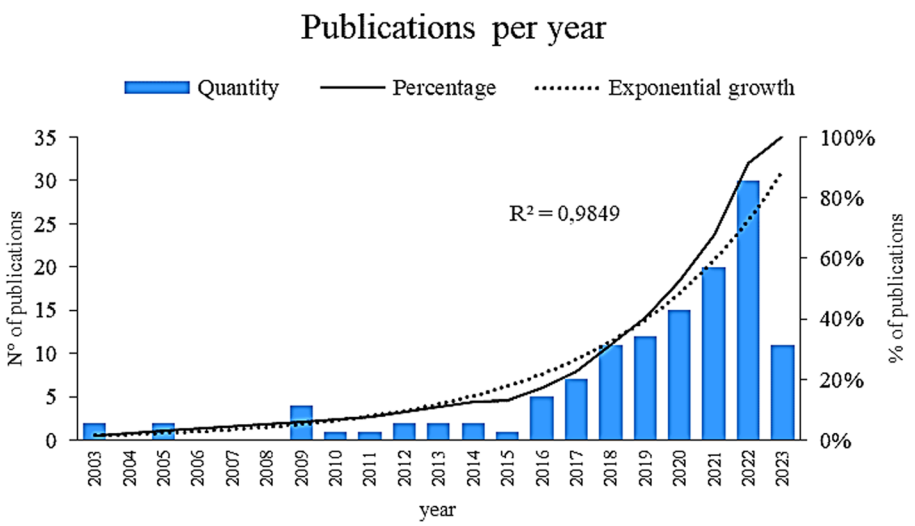

Fig. 2 Publications by year. Compiled from Scopus and Web of Science

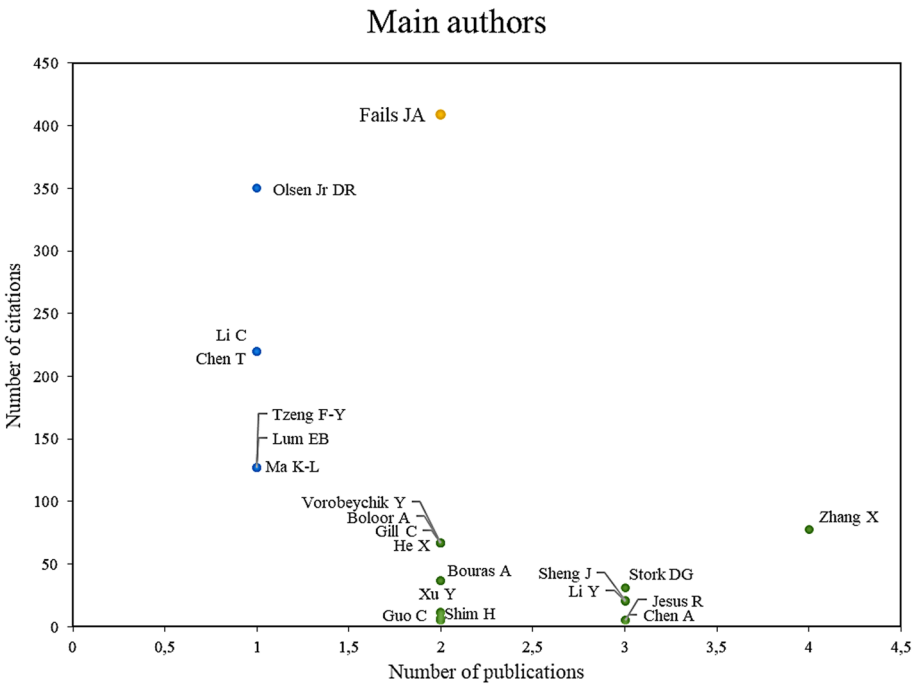

Fig. 3 Main authors. Compiled from Scopus and Web of Science

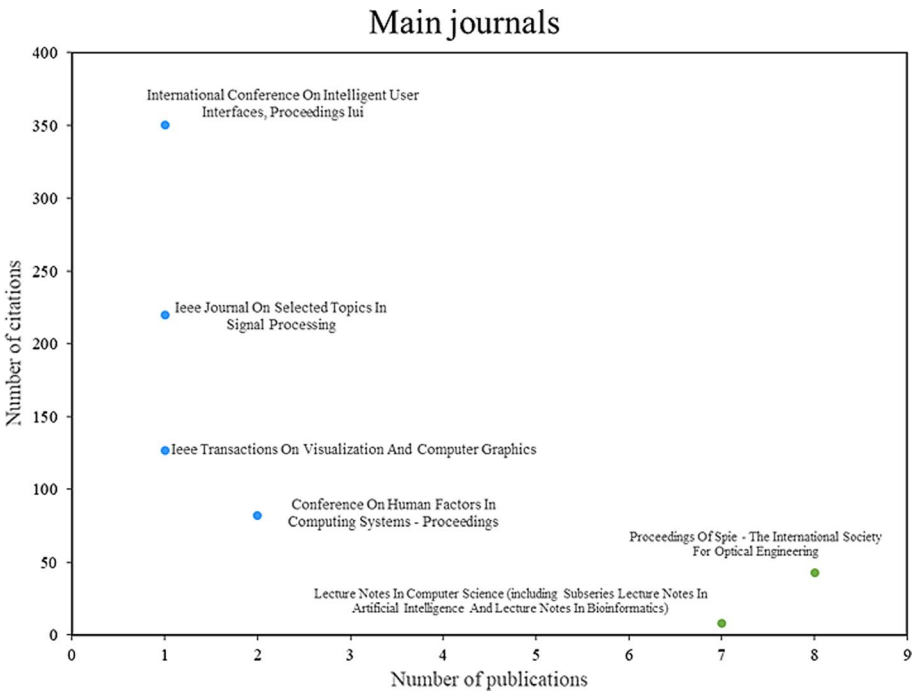

Fig. 4 Top journals. Compiled from Scopus and Web of Science

mainly the journal "Proceedings of Spie - The International Society for Optical Engineering". These results allow a better understanding of the dynamics and approaches of the different journals in the field of deep learning applied to the analysis of artistic styles in paintings.

Two groups of prominent countries were also identified, as shown in Fig. 5. The first group, consisting of China and the United States, is characterized by high scientific productivity and impact on the academic community. The second group, led by Germany, South Korea and India, is characterized by outstanding scientific productivity, although the number of citations is not as relevant as in the first group. These results reflect the leadership and significant contribution of China and the United States in the development of research in the field, while Germany, South Korea and India also emerge as important referents in terms of scientific production related to the subject studied.

The present investigation analyzes the thematic evolution in the literature on the use of machine learning models to predict artistic styles in paintings, as observed in Fig. 6, taking as reference the most used keyword in each year of the study from 2003 to 2023. It was observed that in the first year of the study, 2003, the appearance of terms such as "perceptive user interfaces" stood out. However, in recent years there has been a clear preponderance of topics such as "Artificial Intelligence", "Deep Learning", and "Generative Adversarial Networks", reflecting current trends in research on this topic. These results provide an overview of the progress and changes in the research approach over time, which can be very useful for future work in this area. The terms in this figure were obtained through the mode of key terms from the articles provided by the authors per year. In other words, the

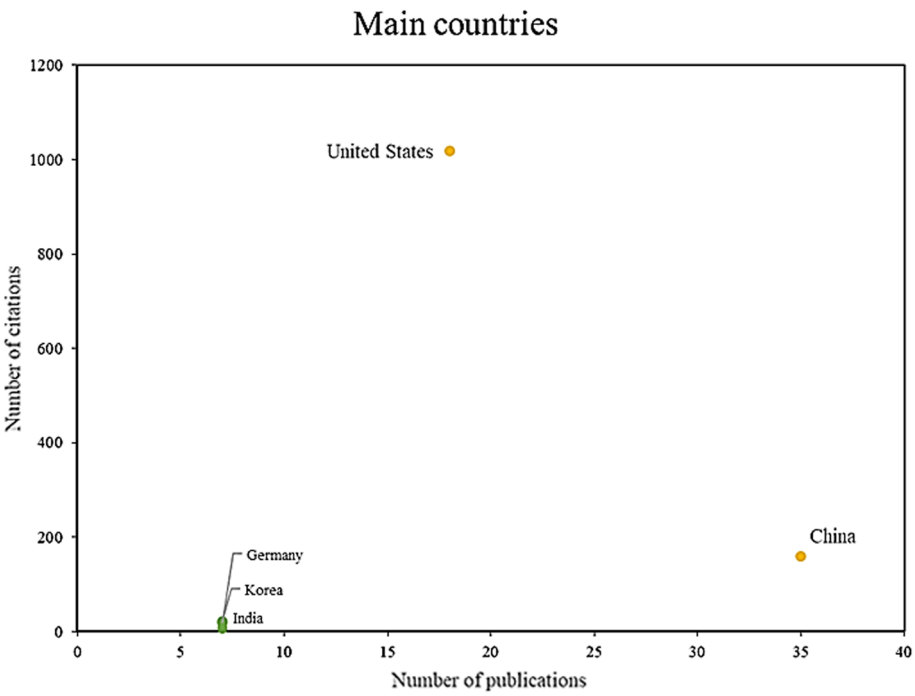

Fig. 5 Main countries. Compiled from Scopus and Web of Science

summation of key terms from the key articles per year is performed, and the most repeated key term per year identifies the progression of the theme each year. This addresses the fourth question related to: What is the thematic evolution derived from the scientific production on the use of machine learning for predicting artistic styles?

Similarly, the literature review provides an analysis of the keyword co-occurrence network in the context of machine learning models for predicting artistic styles in paintings, where 8 different thematic clusters are identified, as shown in Fig. 7. The red cluster stands out as the most prominent and includes key terms such as "deep learning", "computer vision", "cultural heritage", "generative adversarial network", and "convolutional neural networks". Next in importance is the light blue cluster, which includes terms such as "Artificial Intelligence" and "Art Design". The other color clusters, Green, Yellow, Dark Blue, Orange, Lilac, and Pink, reflect different elements of conceptual affinity in this field of study. This addresses the fifth question related to: What are the main thematic clusters on the use of machine learning for predicting artistic styles?

Finally, an analysis based on a Cartesian plane is proposed to measure the frequency of use of keywords on the X-axis and their validity of use on the Y-axis, which allows a detailed observation of four different quadrants, as observed in Fig. 8. The first quadrant of the Cartesian plane, representing the frequency of usage of keywords against the average year of usage, corresponds to emerging and prominent words. These terms, though recent, have seen a rapid surge in usage and have become prominent elements in contemporary communication. In contrast, the second quadrant houses emerging words, indicating that these terms are relatively new and have not yet achieved widespread adoption. This

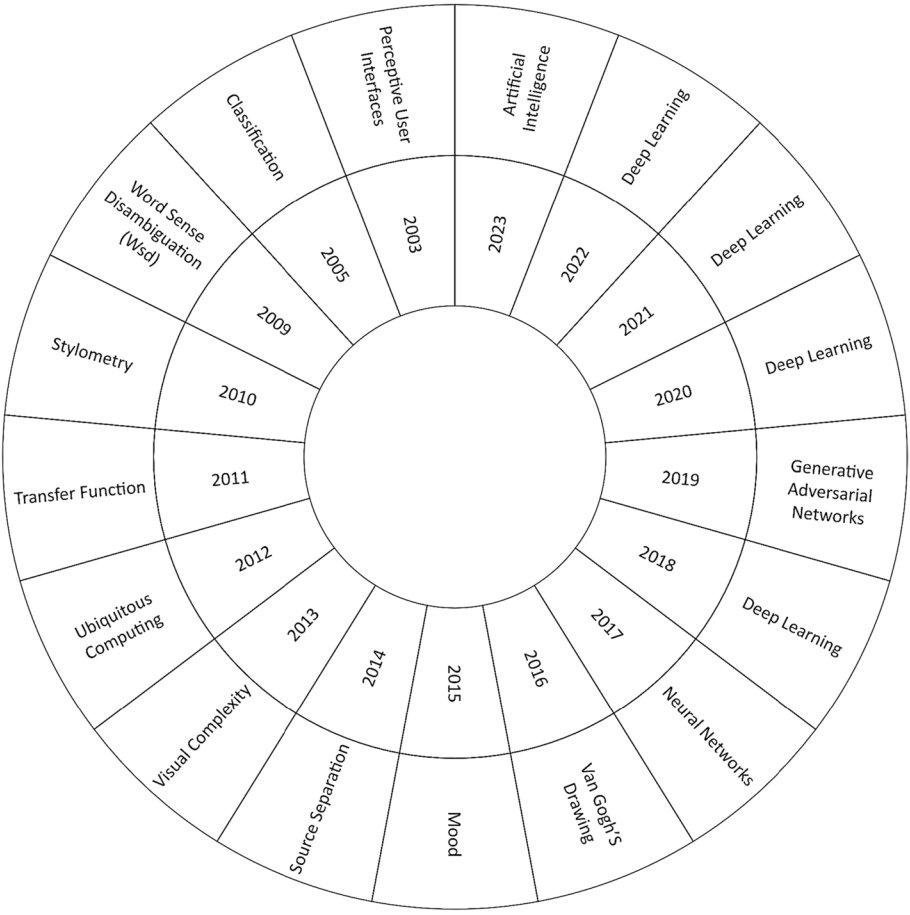

Fig. 6 Thematic evolution. Compiled from Scopus and Web of Science

quadrant suggests a potential for future growth in the popularity of these words, but currently, their presence in conversation is more limited compared to those in the first quadrant.

In quadrant 4, identified as the quadrant of declining concepts, no relevant keywords were found in this particular case. On the other hand, quadrant 2 highlights keywords that have a low frequency of use but a high currency, which classifies them as emerging, including terms such as "Art Design", "Supervised Machine Learning", "Art History", and "Image Generation". In contrast, established and growing concepts such as "Artificial Intelligence" and "Deep Learning" are located in Quadrant 1. This analytical strategy provides a comprehensive view of the evolution and relevance of keywords in the field of deep learning models for predicting artistic styles in paintings. This addresses the sixth and seventh questions related to: What are the growing and emerging keywords in the research field of the use of machine learning for the

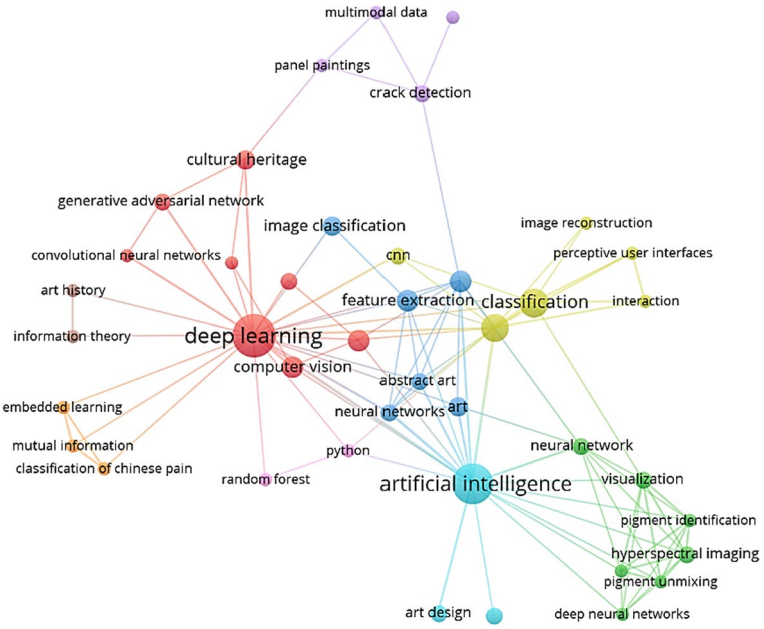

Fig. 7 Keyword co-occurrence network. Own elaboration from Scopus and Web of Science

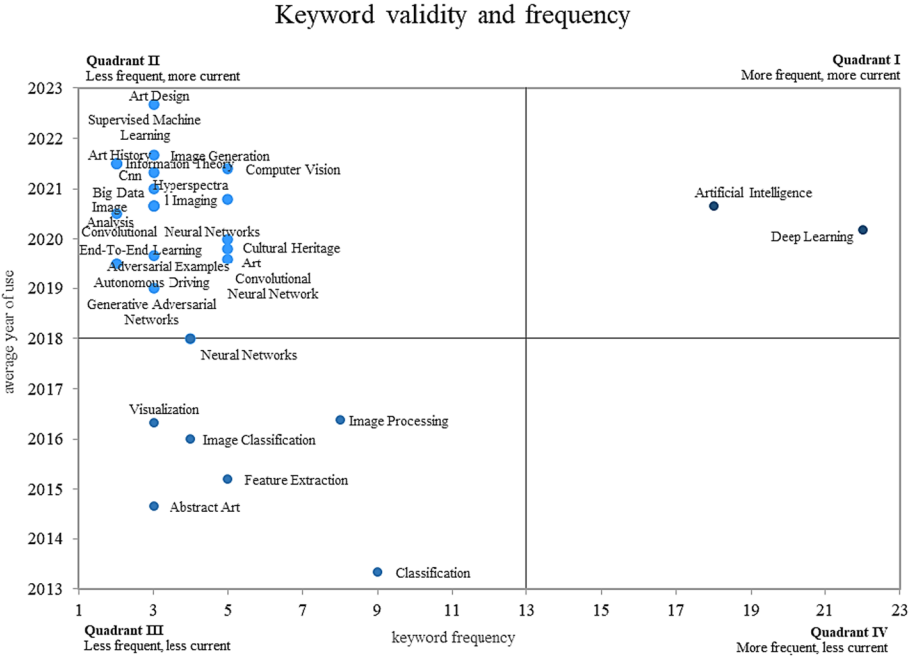

Fig. 8 Validity and frequency of keywords. Own elaboration from Scopus and Web of Science

prediction of artistic styles? and What issues are positioned as protagonists for the design of a research agenda on the use of machine learning for predicting artistic style?

5 Discussion

In this "Discussion" Section, we provide a detailed analysis of the results of the research on the use of machine learning for predicting artistic styles. The practical implications of the results are addressed, considering their relevance and applicability in the artistic field. The limitations of the study are also examined, identifying possible areas for improvement and limitations that could affect the results. A classification of keywords by function is provided to facilitate understanding and organization of the key concepts covered. In addition, the main research gaps identified during the study are highlighted, indicating opportunities for future research in this area. Finally, a research agenda is proposed to guide future work and approaches that can enrich the use of machine learning in artistic style prediction.

5.1 Analysis of the growth of the scientific literature on color analysis by machine learning

During the years 2020, 2021, and 2022, there was a significant surge in scientific production concerning deep learning models for predicting artistic styles in paintings (see Fig. 2). While acknowledging this trend, it's essential to broaden the scope beyond historical art and incorporate contemporary perspectives.

In 2020, two pivotal studies ventured beyond the traditional confines of art, exploring the application of deep learning in diverse fields. In the first study, the authors probed the safety of autonomous driving models, unveiling vulnerabilities in their visual perception systems. This investigation emphasized the imperative of integrating safety into the development of vision-based autonomous driving technologies, resonating not only with the driving domain but also offering insights applicable to the development of machine learning models in contemporary art contexts (Boloor et al. 2020).

On the other hand, through the following relevant research, other authors presented a machine learning methodology focused on master data management in the field of shipbuilding, demonstrating how deep learning can be applied in practical contexts, which may be relevant to the development of models for predicting artistic styles in paintings (Jeong et al. 2020). The use of this technology in such diverse fields suggests its versatility and potential in predicting artistic styles in pictorial works.

In 2021, noteworthy publications emerged, delving into the application of deep learning models for predicting artistic styles in paintings. Some studies tackled the generation of image descriptions for artistic paintings using virtual images, advancing our understanding and prediction of artistic styles. This not only aids in machine learning models' meticulous analysis and description of visual characteristics but also contributes to a more comprehensive understanding of art history and theory, bridging the historical and contemporary facets of art (Lu et al. 2021). Additionally, there was a focus on the broader application of artificial intelligence in image recognition, holding substantial implications for the identification and analysis of artistic styles from images of paintings (Kumar et al. 2021).

Similarly, by 2022, there are other relevant contributions in the field of using machine learning models to predict artistic styles in paintings. One of these contributions, although

it focuses on the analysis of paintings from the automotive context (Fan et al. 2022), has important implications in the scientific field, since the quality of the painting is a crucial aspect in the appreciation of works of art and could benefit from the application of machine learning techniques. Other studies have analyzed these models in other contexts, such as art therapy for children with autism, which highlights the leading role of artificial intelligence in supporting and improving artistic interventions in specific populations (Hu 2022).

5.2 Analysis of research references on painting analysis by machine learning

In the bibliometrics performed on the use of machine learning models to predict artistic styles in paintings, several outstanding authors were identified in terms of productivity and research impact (see Fig. 3). Two pivotal figures, Fails, a primary author in the field, and Olsen, the second most cited, have significantly shaped human-computer interaction. Their impactful work extends beyond traditional boundaries, demonstrating how interactive learning enhances user experiences with intelligent systems, a narrative particularly relevant to predicting artistic styles in paintings (Fails and Olsen 2003a, b, c). Focused on camera-based interaction, their research has been instrumental in deciphering how systems interpret and respond to user movements and gestures, offering potential applications in predicting contemporary artistic styles.

In terms of impact, other notable authors include Li and Chen, who have conducted influential research in the area of Aesthetic Visual Quality Assessment of Paintings, where they have provided a solid foundation for addressing the issue of aesthetics in artistic production through visual analysis. His approach has been recognized for its contribution to the prediction and evaluation of artistic styles in paintings (Li and Chen 2009).

On the other hand, Tzeng, Lum, and Ma have done relevant work in the field of data classification in higher dimensions, which has also been shown to have important implications in predicting artistic styles in paintings, as it could be applied to understanding and predicting artistic patterns in paintings (Tzeng and Lum 2005). In turn, the author Zhang was classified as the most important author in terms of scientific productivity, with publications that stand out thanks to the application of machine learning techniques in the prediction of artistic styles in paintings, especially when using high-resolution data (Zhang et al. 2021).

Scientific journals play a fundamental role in the dissemination and consolidation of knowledge in specific research areas. In the field of deep learning models for predicting artistic styles in paintings, several outstanding journals have been identified in terms of impact and productivity (see Fig. 4). Among them, the International Conference on Intelligent User Interfaces (IUI) has been an important pillar in advancing research in human-computer interaction applied to interactive learning. This conference has been an important forum for presenting relevant papers that have shown how interactive learning can improve user interaction with intelligent systems, which has had direct implications for the development of machine learning models for predicting artistic style in paintings (Fails and Olsen 2003b).

Another prominent journal is the IEEE Journal on Selected Topics in Signal Processing, which has been a benchmark in the evaluation of the aesthetic visual quality of paintings, based on outstanding research whose focus on the evaluation of visual aesthetics has been essential for understanding how machine learning models can capture and analyze artistic features has helped to predict styles in paintings more accurately (Li and Chen 2009).

On the other hand, the Proceedings of SPIE—The International Society for Optical Engineering have been a reference point for research in the analysis of multiple visual features in paintings, especially in the context of authenticating works of art. art, which has been patented in work that has transcended traditional approaches to analyzing works of art and has explored the potential of machine learning techniques to predict artistic styles and authenticate paintings (Irfan and Stork 2009).

In the literature on the use of machine learning models to predict artistic styles in paintings, the United States and China stand out in terms of both productivity and research impact (see Fig. 5). The United States has been a significant source of scientific contributions in this field, as evidenced by works that have addressed relevant aspects for the prediction of artistic styles and demonstrated the applicability of machine learning models in measuring household resilience using high-frequency data (Knippenberg et al. 2019).

For its part, China has shown a growing scientific production on the subject, and one of the outstanding studies has addressed the generation of cartoon images from sketches through the use of Wasserstein conditional adversarial generative networks, which has been relevant to advance in the prediction of artistic styles in paintings (Liu et al. 2018).

In addition, Germany, South Korea, and India have also been important benchmarks in terms of productivity. Germany has contributed significant research in the field of robotics applied to painting, which is key to address the automation of the painting process and its link with artificial intelligence (Gülzow et al. 2020). South Korea, for its part, has been recognized for its focus on the application of machine learning methods in the field of ship design and construction, which has been relevant in advancing the prediction of artistic styles through the application of machine learning approaches in the shipping industry (Jeong et al. 2020). Finally, India has also made important contributions in the field of crack detection in digital images using supervised machine learning approaches, which is important in addressing the challenges of artistic style prediction by applying machine learning techniques in the detection. of specific features in images (Vadicherla and Gadicha 2022).

5.3 Analysis of the thematic evolution in the analysis of paintings by machine learning

The concept of "perceptive user interfaces" played a fundamental role in the early years of research in the field of using machine learning models to predict artistic styles in paintings (see Fig. 6). It was found that this thematic approach allowed researchers to better explore and understand how users perceive and experience machine learning interfaces applied to the analysis of artistic styles. In this sense, (Fails and Olsen 2003b) contributed significantly to the advancement of the field by providing a solid foundation for the initial development of deep learning approaches that took into account the interaction between the user and the model, which facilitated the understanding of aesthetic preferences and the generation of individual art styles.

However, as the field evolved, the conceptual focus shifted to more prominent areas such as "Artificial Intelligence", "Deep Learning", and "Generative Adversarial Networks", leading to further development and refinement of techniques and approaches for predicting artistic styles in paintings.

Regarding "Artificial Intelligence", a growing interest has been highlighted in the application of neural networks for the classification and evaluation of pictorial expressions, which allow greater precision in the identification of artistic styles and in the understanding

of the characteristics of each work, thus contributing to the advancement of the field (Gengenbach and Kerstin 2022).

Regarding "Deep Learning", one of the most studied concepts has been the analysis of emotions in literary painting images, where some authors, in specific contexts, have explored the way in which machine learning techniques have allowed a more precise detection of emotions expressed in paintings, enriching the understanding of the emotional content in artistic works and providing a new perspective to evaluate the impact of artistic styles on the viewer (Zhang et al. 2021).

Finally, "Generative Adversarial Networks" has been another key concept in the current research on artistic style prediction. For example, some work has focused on developing a framework for the restoration and conservation of visual cultural heritage using GAN techniques for the inpainting process. This approach has proven valuable in the restoration of damaged artistic images, which has led to increased recognition of the practical applications of GANs in the preservation of artistic heritage (Jboor et al. 2019).

5.4 Analysis of thematic clusters in the analysis of paintings by machine learning

Bibliometrics is an analytical tool that allows the study of scientific production and thematic relationships between documents. In this sense, a keyword co-occurrence analysis was carried out to identify the main thematic clusters related to the use of machine learning models to predict artistic styles in paintings (see Fig. 7). One of the most prominent clusters, represented by the color red, shows a thematic affinity between terms such as "Deep Learning", "Computer Vision", "Cultural Heritage", "Generative Adversarial Network" and "Convolutional Neural Networks".

This cluster is related to the quantification of visual similarity for artistic styles, as discussed in the work of (Sánchez Santana and Roman-Rangel 2021). In their research, they addressed the quantitative assessment of visual similarity between artistic styles using techniques based on deep learning, providing a solid foundation for understanding how convolutional neural networks and generative adversarial networks can be applied in the field of computer vision and cultural heritage, thus enriching knowledge in this field.

On the other hand, a second relevant cluster has been identified, indicated by the light blue color, which groups terms such as "Artificial Intelligence" and "Art Design" and is of particular interest in the context of artistic design driven by artificial intelligence. Several studios explored this topic in their work, where they evaluated optimal art design using artificial intelligence and machine learning. The research provides valuable insight into how cutting-edge technologies such as artificial intelligence can enrich and enhance the field of artistic design (Wenjing and Cai 2023).

5.5 Analysis of frequency and conceptual validity in the analysis of paintings by machine learning

In quadrant 2 of the Cartesian plane of the current bibliometrics on the use of machine learning models to predict artistic styles in paintings, emerging concepts were found that play a crucial role in the current and near future scientific field. Among them, the term "artistic design" stands out, which has been the key to address the importance of "intelligent product artistic design" based on intelligent devices and machine learning algorithms, which represents an effective and promising practice for the analysis and creation of art (Mengyao and Yu 2023). The synergy between artistic design and intelligent technologies

drives the generation of innovative and creative artworks, with potential applications in various industries and artistic disciplines.

Another emerging concept is "supervised machine learning", which has been validated in studies that have measured the originality of intellectual property assets by estimating the distances between assets, while supervised machine learning involves training algorithms to recognize patterns and make precise decisions, representing a significant advance in the evaluation of artistic quality and the valuation of cultural assets (Ragot 2022).

In addition, in Quadrant 2, the emerging term "Art History" stands out, where some studies propose a novel approach through the use of "Wikiartvectors", a tool that represents styles and colors of works of art for cultural analysis through information theory measures, also referring to the fact that a deep understanding of art history and its relationship with culture is essential for the development of machine learning models capable of capturing the essence and intrinsic meaning of artistic expressions (Srinivasa Desikan et al. 2022).

These emerging concepts, such as "art design," "supervised machine learning," and "art history," have proven to be fundamental in research on predicting artistic styles in paintings using deep learning models. The convergence of intelligent technologies and artistic knowledge is opening new perspectives in the creation, interpretation, and appreciation of art. These advances have the potential to transform the way artists create and express themselves, as well as enrich the understanding of cultural manifestations over time. As research in this area continues to advance, these disciplines are expected to play an even greater role at the forefront of artistic creativity and innovation.

On the other hand, it is noted that in quadrant 1 of the Cartesian plane of bibliometrics on the recognition of artistic styles in paintings by means of automatic learning, growing, leading and consolidated concepts were found in the research field. One of them is "Artificial Intelligence", a discipline that has gained exceptional relevance today and projects a promising future. Regarding this concept, some studies have carried out a comparative analysis of multivariate, statistical, and artificial intelligence methods for the processing of hyperspectral data from paintings, for example, by Picasso, proving to be a powerful tool for interpretation and complex data processing, and its application in the artistic field offers a deeper understanding of the techniques and styles used by artists (Cucci et al. 2021).

Finally, the concept of "deep learning" also occupies a leading place in Quadrant 1 and has given rise to research that explores the understanding of creative intent and color suggestions in illustration based on deep learning, which has revolutionized the ability of machines to learn complex patterns and abstract representations, and its application in the interpretation of artistic creativity is an example of its versatility (Sun and Qin 2021).

5.6 Classification of keywords on painting analysis by machine learning according to their function

Table 2 presents a classification of emerging and growing keywords related to the use of machine learning to predict artistic styles, according to their function. It allows the identification of the main characteristics and applications associated with each category, highlighting areas of interest in constant growth and outstanding approaches in current research.

5.7 Practical implications

Bibliometrics applied to the study of machine learning models for the prediction of artistic styles in paintings has revealed significant practical implications for the scientific

Table 2 Classification of keywords according to their function. Own elaboration from Scopus and Web of Science

Keyword	Associated Tools	Applications	Characteristics
Art Design	Design software	Graphic design, Illustration	Image creation and manipulation
Supervised machine learning	TensorFlow, Scikit-Learn	Estimation of artistic styles	Learning from labeled data
Art history	Research libraries	Art historical analysis	Study and understanding of artistic movements
Image generation	Generative adversarial networks	Abstract art generation	Creating realistic or surreal images
Artificial intelligence	Neural networks, NLP	Data processing	Learning capacity and decision making
Deep learning	Convolutional neural networks	Pattern recognition	Complex feature extraction

community and art professionals. The analysis of the thematic evolution shows a change in the research approach from "Perceptive User Interfaces" to aspects more related to "Artificial Intelligence", "Deep Learning" and "Generative Adversarial Networks". This change reflects the growing importance of artificial intelligence and deep learning in the field of art, suggesting a greater interest in the creation and understanding of artistic works generated by algorithms and machines.

The main thematic cluster identified, which includes terms such as "Deep Learning", "Computer Vision", "Cultural Heritage", "Generative Adversarial Network" and "Convolutional Neural Networks", reveals the conceptual affinity between these terms. This could indicate a convergence of knowledge and research approaches in certain areas, which could be beneficial for the development of more sophisticated and accurate techniques for predicting artistic styles in paintings.

The analysis of the frequency and validity of the keywords highlights the emergence of concepts such as "art design", "supervised machine learning", "art history" and "image generation", suggesting that these topics are gaining relevance in the context of artistic and technological research. These emerging concepts could open up new lines of research and approaches to the analysis and creation of works of art. At the same time, the growing presence of terms such as "Artificial Intelligence" and "Deep Learning" signals a consolidation and advancement of these fields, which may lead to faster progress and more diverse practical applications at the intersection of art and technology.

In addition to the implications mentioned above, the bibliometric study on machine learning models for predicting artistic styles also has important implications for the artistic field in terms of democratizing creativity and exploring new artistic horizons. The increasing incorporation of artificial intelligence and machine learning in the artistic field can open up opportunities for artists and creators who want to experiment with innovative approaches and multidisciplinary collaborations. These technologies provide greater access to advanced creative tools that can broaden participation and diversity in artistic production. Similarly, the use of machine learning algorithms and models in predicting artistic styles can foster the generation of hybrid works that combine human creativity and machine learning capabilities, resulting in unique and surprising artistic expressions.

Another relevant implication for the artistic field is related to the preservation and restoration of cultural heritage. The use of machine learning techniques to analyze and classify historical works of art can be very useful in identifying styles, periods, and authors, contributing to a better understanding and preservation of humanity's artistic heritage. The ability to accurately identify and characterize artistic styles can facilitate the authentication of works of art and aid in the detection of forgeries. This is particularly important in the fields of art history and cultural heritage, where the authenticity and proper conservation of works are of paramount importance. In this way, the use of machine learning to predict artistic styles can have a significant impact on art research and conservation over time, ensuring the preservation of our cultural heritage for future generations.

5.7.1 Challenges and contributions

The Table 3 presents the summary of the main challenges and contributions in the use of machine learning for the art sector.

Table 3 Challenges and contributions in the use of machine learning for the art sector

Challenges	Contributions
Need for more complex techniques	Improvement in result accuracy and reliability
Model interpretation and explanation	Application in evaluating artistic designs using AI and ML
Exploration of style diversity	Identification and visualization of pigments in artworks
Focus on fragments of artworks	Protection of Dunhuang cultural heritage
Lack of understanding model decisions	Creation of artwork catalogs using AI and ML
Analysis of specific techniques for painting style prediction	Enrichment of art teaching with VR and ML
Development of ML techniques capturing diversity in paintings	Enhancement in artistic heritage conservation
Identification of promising trends and approaches	Advancement in understanding art history

5.8 Limitations

The present bibliometrics on the use of machine learning models to predict artistic styles in paintings, based on the PRISMA-2020 methodology and using the Scopus and Web of Science databases, provides a valuable perspective on the evolution and trends in the field. However, there are some limitations that need to be taken into account when interpreting the results. First, the exclusive focus on two databases may have limited the coverage of publications, excluding possible contributions from other relevant sources. Similarly, the selection of keywords may have affected the completeness of the study, excluding emerging or less common terms that could have enriched the analysis.

Furthermore, although the tools used to define bibliometric indicators (Microsoft Excel® and VOSviewer®) are widely recognized, it is important to recognize that each tool has its own limitations and specific methodological approaches that may influence the results. Similarly, focusing on bibliometric indicators of quantity, quality and structure can provide an overview of the field, but does not allow for an in-depth analysis of the intrinsic quality of publications or a complete understanding of thematic evolution.

In conclusion, the present bibliometrics provide a valuable overview of deep learning models applied to the prediction of artistic styles in paintings, but it is important to take into account the aforementioned limitations when interpreting the results. It is suggested that future studies consider expanding the coverage of the databases, adopting a more exhaustive approach in the selection of keywords, and considering multiple bibliometric tools to obtain a more complete and accurate view of the scientific landscape in this area.

The search equation employed across both databases is delimited to the singular concept of “machine learning”. Nonetheless, this restrictive formulation may inadvertently exclude numerous germane terms integral to the broader discourse on the subject. Consequently, the outcomes derived from such a constrained query may lack comprehensiveness, potentially omitting key contributions and nuances within the expansive domain of machine learning research.

5.8.1 Threats to validity in the study

The text provided outlines a comprehensive study based on bibliometric analysis related to the utilization of machine learning models to predict artistic styles in paintings. It discusses various aspects of the research methodology, such as eligibility criteria, sources of information, search strategy, data management, selection process, risk of bias assessment, effect measures, methods of synthesis, assessment of reporting bias, assessment of certainty, and limitations. Considering the study's context, here are the potential threats to validity in this research:

- Selection Bias: Despite defining clear eligibility criteria, there could be biases in the selection process. The exclusion of certain terms or databases might lead to the omission of relevant studies, affecting the comprehensiveness of the findings.
- Publication Bias: The study's reliance on specific databases like Scopus and Web of Science may lead to the exclusion of pertinent studies present in other databases. This could result in an incomplete representation of the existing literature on the topic.
- Search Strategy Limitations: Limiting the search to specific keywords might overlook publications that use different terminology or emerging concepts related to machine learning and artistic styles. This could potentially exclude valuable contributions from the analysis.
- Incomplete Data Interpretation: Although the study performs a detailed analysis of bibliometric indicators, it may not delve deeply into the qualitative aspects of the included publications. Assessing the intrinsic quality of studies might provide a more comprehensive understanding of the field.
- Tool Limitations: Reliance on specific tools like Microsoft Excel® and VOSviewer® might introduce biases or limitations in data collection, processing, and visualization. These tools have their own methodological constraints that could influence the findings.
- Temporal Bias: The analysis of trends and growth might not capture recent developments due to a potential time lag between the publication of the included studies and the date of the analysis.
- Incomplete Coverage: Focusing solely on machine learning models for predicting artistic styles might overlook interdisciplinary studies or innovative approaches that bridge other domains with art prediction.
- Scope Limitation: The study's focus on bibliometric analysis restricts a detailed examination of the content quality, interpretations, and practical implications of the included publications.

To enhance the validity of the research and mitigate these threats:

- Consider broadening the search scope to include additional databases or sources beyond Scopus and Web of Science.
- Employ more diverse search terms to ensure inclusivity of all relevant studies.

Table 4 Research gaps. Compiled from Scopus and Web of Science

Category	Gaps	Justification	Questions for future researchers
Thematic gaps	(a) Lack of focus on modern and contemporary art.	Most studies have focused on historical artistic styles, leaving a gap in the application of machine learning models to more recent art.	How can machine learning models be adapted to predict artistic style in modern and contemporary works?
	(b) Limiting the inclusion of non-Western art styles.	Many studies have focused on Western styles, leaving aside artistic traditions from other cultures, which may affect the generalizability of the models.	What specific approaches can be used to incorporate non-Western art styles into prediction with deep learning models?
	(c) Lack of research on predicting styles in different artistic techniques.	Existing models tend to focus on oil painting, but there are other artistic techniques such as watercolor, graphite, etc. that could also benefit from style analysis.	How can the models be adapted to predict artistic styles in different painting techniques?
Geographic gaps	(a) Low representation of artists and art collections from non-Western regions.	The databases used in many studies tend to be dominated by works by Western artists, which can introduce cultural bias and limit stylistic diversity.	What efforts can be made to collect and use data from artists and art collections from non-Western regions in future studies?
	(b) Regional differences in the valuation of art.	Criteria for defining artistic styles may vary by region and culture, which may require specific modeling approaches for each geographic context.	How can style prediction models account for regional differences in art appreciation and perception?
Interdisciplinary gaps	(a) Limited integration of art theory into deep learning models.	Many models are based only on visual characteristics, without taking into account the theoretical and conceptual context of art, which could enrich the understanding of artistic styles.	How can art theory concepts be incorporated into the formulation of features and metrics for style prediction with deep learning?
	(b) Little collaboration between deep learning experts and art theory experts.	Research in this area is often conducted in separate disciplinary silos, which could limit the development of more comprehensive and accurate approaches.	How can we foster closer collaboration between deep learning researchers and art theorists to improve the quality of style predictions?

Table 4 (continued)

Category	Gaps	Justification	Questions for future researchers
Temporary gaps	(a) Limitations in long-term evaluation of the effectiveness of predictive models.	Most studies focus on short-term assessment of model accuracy, but a deeper understanding of how models hold up and generalize over time is needed.	How can art style prediction models be evaluated and improved over time to ensure their long-term effectiveness?
	(b) Lack of longitudinal studies on the evolution of artistic styles.	Art and styles evolve over time, but few studies have examined the ability of machine learning models to capture and predict these evolutions over decades.	What methodological approaches could be used to conduct longitudinal studies that analyze the evolution of artistic styles and the effectiveness of predictive models?

- Supplement bibliometric analysis with qualitative assessments to gauge the depth and quality of included publications.
- Validate findings by cross-referencing with other independent reviews or studies conducted on similar topics.

5.9 Research gaps

Table 4 shows the main research gaps identified in the area of using machine learning to predict artistic style that need to be addressed in future research. These gaps highlight areas and aspects that have not yet been fully explored or understood in the scientific

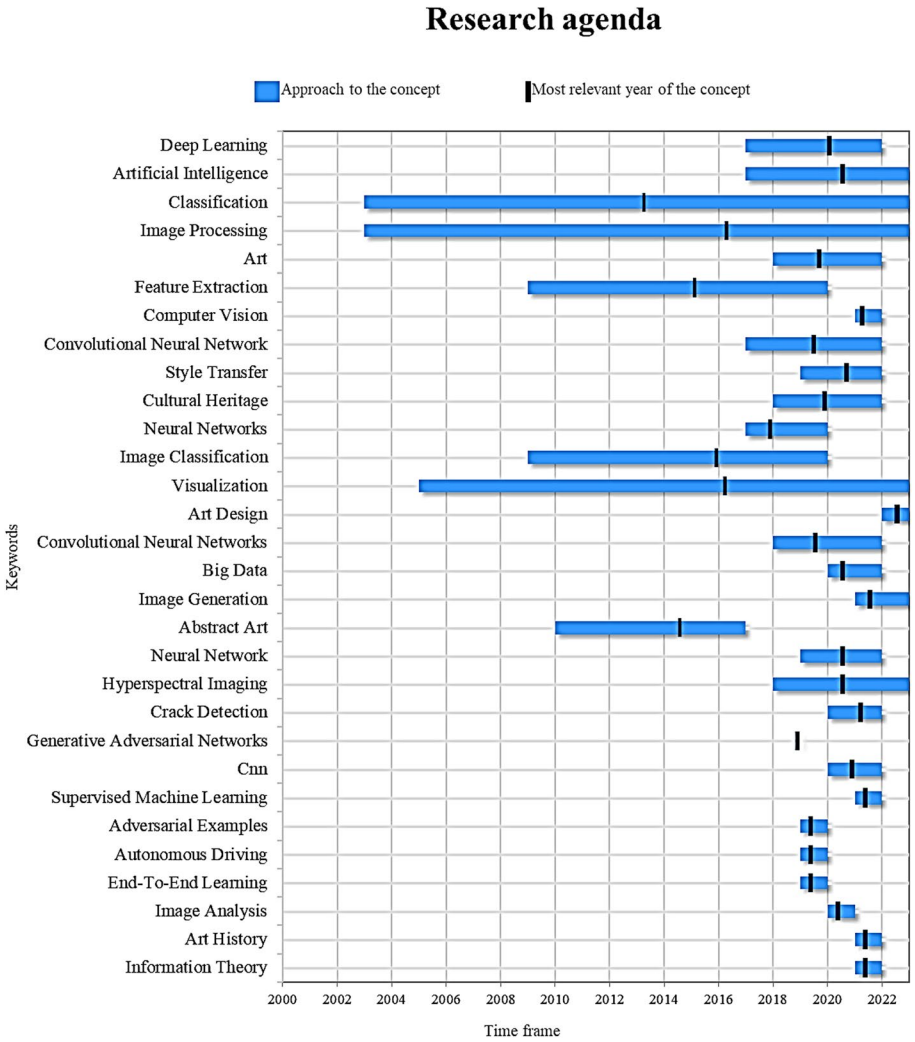

Fig. 9 Research agenda. Compiled from Scopus and Web of Science

literature. Filling these gaps will improve the techniques and approaches used, as well as the understanding of the applicability and effectiveness of machine learning in predicting artistic styles. It will also allow the development of more accurate and advanced models that will contribute significantly to the field of artificial intelligence applied to art.

5.10 Research agenda

Finally, through Fig. 9, the proposed research agenda is presented, which includes the main keywords that have been used in the scientific literature, implying, predominantly, the main growing keywords identified in the analysis. of frequency and validity (see Fig. 8).

The application of artificial intelligence in deep learning models has been a significant advance in the prediction of artistic styles in paintings. AI has revolutionized the ability to analyze and classify works of art, allowing the identification of stylistic characteristics with unprecedented accuracy. In the future, research can focus on developing more sophisticated algorithms that incorporate different classification approaches, such as convolutional neural networks and adversarial deep learning. In addition, visualization of the results and internal processes of the models is essential for a deep understanding of stylistic analysis in the artistic domain.

6 Conclusions

The bibliometrics carried out on the use of machine learning models to predict artistic styles in paintings have yielded highly relevant results. A significant growth of interest in this field has been observed in the years 2020, 2021 and 2022, indicating a constant increase of attention and commitment of the scientific community to this field of study. This increase in the production of scientific articles has been exponential, which allows us to conclude that the scientific literature has a sustained growth of research on the subject, positioning it as relevant for the near future.

Regarding the main research references, the author Fails was identified as a leading figure in the literature, indicating his relevance and contribution to the understanding of machine learning models applied to the prediction of artistic styles in paintings. Likewise, it was found that the journals “Conference On Intelligent User Interfaces” and “IEEE Journal on Select Topics in Signal Processing” are leaders in the publication of research on this topic, giving them a fundamental role in the dissemination of knowledge in the field. On the other hand, the most prominent countries in scientific production are the United States and China, reflecting their strong commitment and leadership in research related to this topic.

The analysis of the thematic evolution revealed a transition in the orientation of the studies from a specialization in “Perceptive User Interfaces” to a greater focus on topics of “Artificial Intelligence” and “Deep Learning”. This change allows us to conclude that there is an adaptation of researchers to current trends in research on the use of machine learning

models to predict artistic styles in paintings, which contributes to the advancement and enrichment of knowledge in the discipline.

On the other hand, a thematic cluster stands out in the research, composed of terms such as "Deep Learning", "Computer Vision", "Cultural Heritage", "Genera-tive Adversarial Network" and "Convolutional Neural Networks", pointing out a conceptual affinity between these key themes, which suggests priority focus areas for future research and allows us to conclude on crucial elements about one of the leading concepts of scientific literature such as Deep Learning.

With regard to the keywords that are currently trending, a solid domain of "Artificial Intelligence" and "Deep Learning" has been identified as consolidated concepts and protagonists in the field. Similarly, emerging terms such as "Art Design", "Supervised Machine Learning", "Art History", and "Image Generation" were observed, highlighting the evolution and expansion of the field into new areas of research and applications.

The article primarily focuses on classification and the main journals in the field but covers much additional critical information. It provides a detailed classification of emerging keywords related to machine learning in predicting artistic styles, emphasizing their growth and highlighted approaches. Practical implications range from impacting the scientific community and art to democratizing creativity and preserving cultural heritage. Additionally, it outlines study limitations and offers recommendations to enhance research validity. Lastly, it identifies research gaps and proposes a future agenda spanning from developing advanced algorithms to exploring image generation and classification techniques.

The study on using machine learning for predicting artistic styles in paintings offers a comprehensive overview of the field's growth and evolution. Through bibliometric analysis, it highlights significant scientific advancements and the evolution of interest in machine learning techniques for this purpose. It identifies emerging themes like "Artificial Intelligence" and "Deep Learning," guiding future research directions. Additionally, the study emphasizes key references, influential authors, and noteworthy journals, providing a roadmap for researchers to navigate the current landscape of knowledge and potentially enhance the visibility of their work. Moreover, the comparative analysis among countries fosters global collaborations, offering insights into regional contributions and cultural perspectives, while the exploration of thematic evolution and keyword networks inspires innovative research directions and strategies for further exploration of promising concepts.

Finally, the analysis conducted addresses the evolution of the use of machine learning (ML) models in predicting artistic styles, highlighting a shift from user perception approaches towards advanced tools such as deep learning. The emphasis on neural networks, particularly in pattern recognition, underscores the use of design software for image manipulation. Moreover, gaps in existing research are acknowledged, pointing out the need

for more comprehensive ML techniques to fully capture the diversity of artistic styles, as well as the importance of interpreting the features learned by these models and further exploring the role of AI in art authentication and preservation.

The review highlights structured questions covering temporal trends, growth patterns, influential research references, thematic evolution, emerging keyword clusters, and key topics shaping the research agenda in this field. The chronological presentation of prominent works from different decades offers a comprehensive view of the advancement of machine learning in predicting artistic styles. In this way, a wide range of literature is synthesized, proposing a comprehensive research agenda based on bibliometric analysis, providing some insights for future interdisciplinary research in this area.

7 Appendix

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
1.	Fails JA, Olsen Jr DR	2003	International Conference On Intelligent User Interfaces, Proceedings Iui	350	United States	Interactive machine learning	Conference Paper	Classification; Image processing; Interaction; Machine learning; Perceptive user interfaces
2.	Li C, Chen T	2009	Ieee Journal On Selected Topics In Signal Processing	220	United States	Aesthetic visual quality assessment of paintings	Article	Aesthetics; Classification; Feature extraction; Visual quality assessment
3.	Tzeng F-Y, Lum EB, Ma K-L	2005	Ieee Transactions On Visualization And Computer Graphics	127	United States	An intelligent system approach to higher-dimensional classification of volume data	Article	Classification; Graphics hardware; Machine learning; Transfer functions; User interface design; Visualization; Volume rendering

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
4.	Liu YF, Qin ZC, Wan T, Luo ZB	2018	Neurocomputing	69	China	Auto-painter: Cartoon image generation from sketch by using conditional Wasserstein generative adversarial networks	Article	Auto-painter; GAN; Wasserstein distance; WGAN; Deep learning; Neural networks
5.	Fails JA, Olsen DR	2003	Conference On Human Factors In Computing Systems - Proceedings	59	United States	A design tool for camera-based interaction	Conference Paper	Classification; Image processing; Interaction; Machine learning; Perceptive user interfaces
6.	Polatkan G, Jafarpour S, Brasoveanu A, Hughes S, Daubechies I	2009	Proceedings - International Conference On Image Processing, Icip	44	United States	Detection of forgery in paintings using supervised learning	Conference Paper	Blur identification; Digital painting analysis; Forgery detection; Hidden markov trees; Image classification
7.	Knippenberg E, Jensen N, Constas M	2019	World Development	41	United States	Quantifying household resilience with high frequency data: Temporal dynamics and methodological options	Article	Africa; Food security; Machine learning; Malawi; Resilience; Shocks
8.	Boloor A, Garimella K, He X, Gill C, Vorobeychik Y, Zhang X	2020	Journal Of Systems Architecture	38	United States	Attacking vision-based perception in end-to-end autonomous driving models	Article	Adversarial examples; Autonomous driving; Bayesian optimization; End-to-end learning; Machine learning

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
9.	Lurig MD, Donoughe S, Svensson EI, Porto A, Tsuboi M	2021	Frontiers In Ecology And Evolution	37	United States	Computer Vision, Machine Learning, and the Promise of Phenomics in Ecology and Evolutionary Biology	Review	computer vision; machine learning; phenomics; high-throughput phenotyping; high-dimensional data; image analysis; image segmentation; measurement theory
10.	Agarwal S, Davé R, Bassett BA	2018	Monthly Notices Of The Royal Astronomical Society	37	Africa	Painting galaxies into dark matter haloes using machine learning	Article	Cosmology: theory; Galaxies: evolution; Large-scale structure of Universe
11.	Falomir Z, Museros L, Sanz I, Gonzalez-Abril L	2018	Expert Systems With Applications	30	Spain	Categorizing paintings in art styles based on qualitative color descriptors, quantitative global features and machine learning (QArt-Learn)	Article	Art; Color naming; Color similarity; Machine learning; Qualitative modelling; Support vector machines
12.	Boloor A, He X, Gill C, Vorobeychik Y, Zhang X	2019	2019 Ieee International Conference On Embedded Software And Systems, Icess 2019	29	United States	Simple physical adversarial examples against end-to-end autonomous driving models	Conference Paper	Adversarial examples; Autonomous driving; End-to-end learning; Machine learning

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
13.	Sanhudo L, Calvetti D, Martins JP, Ramos NMM, Mêda P, Gonçalves MC, Sousa H	2021	Journal Of Building Engineering	28	Portugal	Activity classification using accelerometers and machine learning for complex construction worker activities	Article	Activity classification; Construction workers; Productivity analysis; Supervised machine learning; Wearable accelerometers
14.	Bryan NJ, Mysore GJ, Wang G	2014	Conference On Human Factors In Computing Systems - Proceedings	23	United States	ISSE: An interactive source separation editor	Conference Paper	Audio interface; Intelligent user interface; Interactive machine learning; Source separation
15.	Irfan M, Stork DG	2009	Proceedings Of Spie - The International Society For Optical Engineering	23	United States	Multiple visual features for the computer authentication of Jackson Pollock's drip paintings: Beyond box-counting and fractals	Conference Paper	Art authentication; Box-counting algorithm; Fractal image analysis; Jackson Pollock; Painting analysis; Pattern recognition
16.	Belhi A, Bouras A, Foufou S	2018	Applied Sciences-basel	20	France	Leveraging Known Data for Missing Label Prediction in Cultural Heritage Context	Article	cultural heritage; convolutional neural networks; multimodal classification; digital heritage; digital preservation
17.	Folego G, Gomes O, Rocha A	2016	Proceedings - International Conference On Image Processing, Icip	20	Brazil	From impressionism to expressionism: Automatically identifying van Gogh's paintings	Conference Paper	CNN-based authorship attribution; Data-driven painting characterization; Painter attribution

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
18.	Jeong JH, Woo JH, Park J	2020	International Journal Of Naval Architecture And Ocean Engineering	17	Korea	Machine Learning Methodology for Management of Shipbuilding Master Data	Article	Big data; Machine learning; Master data; Production management; Shipbuilding; Statistical analysis
19.	Jboor NH, Belhi A, Al-Ali AK, Bouras A, Jaoua A	2019	2019 Ieee Jordan International Joint Conference On Electrical Engineering And Information Technology, Jeeit 2019 - Proceedings	17	France	Towards an Inpainting Framework for Visual Cultural Heritage	Conference Paper	Cultural Heritage; Deep Learning; Generative Adversarial Networks; Image Inpainting
20.	Guo X, Kurita T, Muraki Asano C, Asano A	2013	2013 Ieee International Conference On Image Processing, Icip 2013 - Proceedings	13	Japan	Visual complexity assessment of painting images	Conference Paper	Classification; Feature extraction; Machine learning; Perception; Visual complexity
21.	Zhang SB, Yang J, Xu Y, Chen XP, Su Y, Sun Y, Zhou X, Li YJ, Lu DR	2020	Astrophysical Journal Supplement Series	12	China	Searching for Molecular Outflows with Support Vector Machines: The Dark Cloud Complex in Cygnus	Article	Stellar jets; Astronomical object identification; Molecular clouds

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
22.	Klavans JL, Sheffield C, Abels E, Lin J, Passonneau R, Sidhu T, Soergel D	2009	Multimedia Tools And Applications	12	United States	Computational linguistics for metadata building (CLiMB): Using text mining for the automatic identification, categorization, and disambiguation of subject terms for image metadata	Article	Image access; Lexical disambiguation; Metadata extraction; Natural language processing (NLP); Subject cataloging; Word sense disambiguation (WSD)
23.	Liu J, Dong W, Zhang X, Jiang Z	2017	Multimedia Tools And Applications	10	China	Orientation judgment for abstract paintings	Article	Abstract paintings; Art theory; Feature extraction; Image classification; Orientation judgment
24.	Sheng J, Song C, Wang J, Han Y	2019	Ieee Access	9	China	Convolutional Neural Network Style Transfer towards Chinese Paintings	Article	Chinese paintings; convolutional neural network; restrictions; style transfer
25.	Azevedo H, Belo JPR, Romero RAF	2017	Proceedings - 2017 Lars 14th Latin American Robotics Symposium And 2017 5th Sbr Brazilian Symposium On Robotics, Lars-sbr 2017 - Part Of The Robotics Conference 2017	8	Brazil	Cognitive and robotic systems: Speeding up integration and results	Conference Paper	Cognition; Human-Robot Interaction; Ontology; Robotic Simulation; Social Robotics

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
26.	Li Y	2012	2012 Ieee Congress On Evolutionary Computation, Cec 2012	8	China	Adaptive learning evaluation model for evolutionary art	Conference Paper	Adaptive learning; computational aesthetic; evolutionary art; feature selection; interactive evolutionary computation
27.	Kandemir M, Kaski S	2012	Icmi'12 - Proceedings Of The Acm International Conference On Multimodal Interaction	8	Finland	Learning relevance from natural eye movements in pervasive interfaces	Conference Paper	Eye tracking; Information retrieval; Midas touch; Object selection; Pervasive computing; Proactive interfaces; Ubiquitous computing
28.	Mao WL	2022	Neural Computing & Applications	7	China	Video analysis of intelligent teaching based on machine learning and virtual reality technology	Article	Machine learning; Virtual reality technology; Oil painting art; Teaching video analysis
29.	Gulzow JM, Paetzold P, Deussen O	2020	Applied Sciences-basel	7	Germany	Recent Developments Regarding Painting Robots for Research in Automatic Painting, Artificial Creativity, and Machine Learning	Article	robotics; painting; art; generative method; brush; brushstroke; data collection
30.	Fan C, Zhang P, Wang S, Hu B	2018	Proceedings Of Spie - The International Society For Optical Engineering	7	China	A study on classification of mineral pigments based on spectral angle mapper and decision tree	Conference Paper	Decision tree; Hyperspectral imaging; Mineral pigments; Spectral angle mapper

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
31.	Smirnov S, Eguizabal A	2018	2018 Ieee International Conference On Metrology For Archaeology And Cultural Heritage, Metroarchaeo 2018 - Proceedings	7	Germany	Deep learning for object detection in fine-Art paintings	Conference Paper	automatic annotation; deep learning; digitized fine-Art paintings; object detection.
32.	Sheng J, Li Y	2019	Journal Of Electronic Imaging	6	United States	Classification of traditional Chinese paintings using a modified embedding algorithm	Article	classification of Chinese paintings; convolutional neural network-based feature description; embedded learning; feature importance; mutual information
33.	Cui Y, Wang W	2019	Proceedings Of 2019 Ieee International Conference On Artificial Intelligence And Computer Applications, Icaica 2019	6	China	Colorless Video Rendering System via Generative Adversarial Networks	Conference Paper	convolutional neural networks; deep learning; generative adversarial networks; image recoloring; self-attention GAN
34.	Li Y, Sheng J, Hua B	2018	Jisuanji Fuzhu Sheji Yu Tuxingxue Xuebao/ journal Of Computer-aided Design And Computer Graphics	6	China	Improved Embedded Learning for Classification of Chinese Paintings [中国画分类的改进嵌入式学习算法]	Article	Classification of Chinese paintings; Deep learning; Embedded learning; Mutual information

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
35.	Andrzejewski D, Stork DG, Zhu X, Spronk R	2010	Proceedings Of Spie - The International Society For Optical Engineering	6	Canada	Inferring compositional style in the neo-plastic paintings of Piet Mondrian by machine learning	Conference Paper	Abstract art; Composition principles; Machine learning; Neo-plastic painting; Piet Mondrian; Stylometry
36.	Lu Y, Guo C, Dai X, Wang F-Y	2021	Proceedings 2021 Ieee 1st International Conference On Digital Twins And Parallel Intelligence, Dtpi 2021	5	China	Image captioning on fine art paintings via virtual paintings	Conference Paper	Fine art paintings; Image captioning; Style transfer
37.	Chiou T	2020	Journal Of Intellectual Property, Information Technology And E-commerce Law	5	Greece	Copyright lessons on Machine Learning: What impact on algorithmic art?	Article	Adaptation right; Algorithmic art; Artificial intelligence; Big Data; Copyright; Copyright exceptions; Copyrighted works; DSM Directive; Infosoc Directive; Machine learning; Reproduction right; Text and data mining
38.	Kumar M, Sharma S, Chaudhary D, Prakash S	2021	2021 International Conference On Advance Computing And Innovative Technologies In Engineering, Icacite 2021	4	India	Image Recognition Using Artificial Intelligence	Conference Paper	Artificial Intelligence; Image Processing; Python

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
39.	Comert C, Ozbayoglu M, Kasnakoglu C	2021	2021 7th International Conference On Mechatronics And Robotics Engineering, Icmre 2021	4	Turkey	Painter Prediction from Artworks with Transfer Learning	Conference Paper	artists classification; convolutional neural network; transfer learning
40.	Cucci C, Barucci A, Stefani L, Picollo M, Jiménez-Garnica R, Fuster-Lopez L	2021	Proceedings Of Spie - The International Society For Optical Engineering	4	Spain	Reflectance Hyperspectral data processing on a set of Picasso paintings: Which algorithm provides what? A comparative analysis of multivariate, statistical and artificial intelligence methods	Conference Paper	Artificial intelligence; Deep learning; Machine learning; Painting materials mapping; Picasso; Pigments identification; Reflectance hyperspectral imaging; VNIR-SWIR reflectance spectroscopy
41.	Angheluţă LM, Chiroşca A	2020	Romanian Reports In Physics	4	Romania	Physical degradation detection on artwork surface polychromies using deep learning models	Article	Cultural heritage; Deep learning; Image analysis; Photogrammetry; Physical damage monitoring
42.	Diren DD, Boran S, Cil I	2020	Scientia Iranica	4	Turkey	Integration of machine learning techniques and control charts in multivariate processes	Article	Multivariate control chart; Naive Bayes-kernel; K-nearest neighbor; Decision tree; Artificial neural networks; Multi-layer perceptron; Deep learning

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
43.	Chen A, Jesus R, Villarigues M	2019	Lecture Notes In Computer Science (including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	4	Portugal	Using Deep Learning Techniques for Authentication of Amadeo de Souza Cardoso Paintings and Drawings	Conference Paper	AlexNet; Art; Artificial intelligence; Authentication; Convolutional Neural Network; Drawings; Machine learning; Neural network; Paintings
44.	Chen S, Wong NH, Zhang W, Ignatius M	2023	Building And Environment	3	China	The impact of urban morphology on the spatiotemporal dimension of estate-level air temperature: A case study in the tropics	Article	Air temperature; Supervised learning; Temporal; Tropics; Urban morphology
45.	Dobbs T, Benedict A, Ras Z	2022	Ai And Society	3	Poland	Jumping into the artistic deep end: building the catalogue raisonne	Article	AI; Catalogue raisonné; Convolutional neural networks; Deep learning; ImageNet; Painting/artist classification; ResNet
46.	Zhang J, Duan Y, Gu X	2021	Frontiers In Psychology	3	China	Research on Emotion Analysis of Chinese Literati Painting Images Based on Deep Learning	Article	Chinese literati painting; computer vision; deep learning; emotional analysis; machine learning
47.	Surapaneni S, Syed S, Lee LY	2020	2020 Systems And Information Engineering Design Symposium, Sieds 2020	3	United States	Exploring Themes and Bias in Art using Machine Learning Image Analysis	Conference Paper	CNNs; deep learning; image classification

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
48.	Xie N, Zhao T, Yang Y, Shen HT	2019	Multimedia Tools And Applications	3	China	Web-based SBLR method of multimedia tools for computer-aided drawing	Article	Artistic stylization; CSCW; Multimedia tools; PGPE; SBR
49.	Zeng Y, Gong Y	2019	International Conference On Digital Signal Processing, Dsp	3	China	Nearest Neighbor based Digital Restoration of Damaged Ancient Chinese Paintings	Conference Paper	ancient Chinese paintings; Damage detection; digital restoration; nearest neighboring algorithm
50.	Sahai T, Mathew G, Surana A	2017	Ifac-papersonline	3	United States	A chaotic dynamical system that paints and samples	Conference Paper	Bayesian methods; Multi-agent systems; Particle filtering/ Monte Carlo methods
51.	Kang D, Shim H, Yoon K	2015	2015 Frontiers Of Computer Vision, Fcv 2015	3	Korea	Mood from painting: Estimating the mood of painting by using color image scale	Conference Paper	color combinations; color image scale; mood; painting
52.	Rea DJ, Igarashi T, Young JE	2014	Hai 2014 - Proceedings Of The 2nd International Conference On Human-agent Interaction	3	Japan	Paint board-Prototyping interactive character behaviors by digitally painting storyboards	Conference Paper	End-user programming; Interactive systems; Interface design; Machine learning; Prototyping; Sketch interface
53.	Yu T, Lin C, Zhang S, Wang C, Ding X, An H, Liu X, Qu T, Wan L, You S, Wu J, Zhang J	2022	International Journal Of Computer Vision	2	Netherlands	Artificial Intelligence for Dunhuang Cultural Heritage Protection: The Project and the Dataset	Article	Artificial intelligence; Computer vision; Cultural heritage protection; Dunhuang

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
54.	Califano A, Foti P, Berto F, Baiesi M, Bertolin C	2022	Procedia Structural Integrity	2	Norway	Predicting damage evolution in panel paintings with machine learning	Conference Paper	crack; cultural heritage; Machine learning; panel paintings; strain-energy density; XGBoost
55.	Stork DG, Bourached A, Cann GH, Griffiths R-R	2021	Is And T International Symposium On Electronic Imaging Science And Technology	2	United Kingdom	Computational identification of significant actors in paintings through symbols and attributes	Conference Paper	Artificial intelligence; Computational art analysis; Computer-assisted connoisseurship; Deep neural networks; Religious symbols and attributes; Semantic image analysis; Visual semiotics
56.	Yi D, Guo C, Bai T	2021	Proceedings 2021 Ieee 1st International Conference On Digital Twins And Parallel Intelligence, Dtpi 2021	2	China	Exploring painting synthesis with diffusion models	Conference Paper	Diffusion models; Image generation; Painting synthesis
57.	Sánchez Santana P, Roman-Rangel E	2021	Lecture Notes In Computer Science (including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	2	Mexico	Quantifying Visual Similarity for Artistic Styles	Conference Paper	Artistic style; Computer vision; Deep learning

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
58.	Chapman C, Parker S, Parsons S, Seales WB	2021	Communications In Computer And Information Science	2	United States	Using METS to Express Digital Provenance for Complex Digital Objects	Conference Paper	3D modeling; Cultural heritage; Digital libraries; Digital provenance; Herculaneum papyri; Metadata; METS; Virtual unwrapping
59.	Kim J, Jun JY, Hong M, Shim H, Ahn J	2019	International Archives Of The Photogrammetry, Remote Sensing And Spatial Information Sciences - Isprs Archives	2	Korea	CLASSIFICATION of OIL PAINTING USING MACHINE LEARNING with VISUALIZED DEPTH INFORMATION	Conference Paper	Artist Classification; Machine Learning; Painting Analysis; RTI; Visualized Depth Information
60.	Zhao R, Ratchev S, Drouot A	2018	Sae International Journal Of Materials And Manufacturing	2	France	Classification of Contact Forces in Human-Robot Collaborative Manufacturing Environments	Article	Human-robot collaborative manufacturing; Contact force classification; Machine learning
61.	Karagiannis GT, Apostolidis GK	2016	Proceedings Of Spie - The International Society For Optical Engineering	2	Greece	Investigation of stratigraphic mapping in paintings using micro-Raman spectroscopy	Conference Paper	overpainting; Raman spectroscopy; spectra clustering; stratigraphic mapping imaging

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
62.	Zeng Y, Tang J, van der Lubbe JCA, Loog M	2016	Lecture Notes In Computer Science (including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	2	Netherlands	Learning algorithms for digital reconstruction of Van Gogh's drawings	Conference Paper	Drawing reconstruction; Machine learning; Reproduction; Van Gogh's drawing
63.	Filipiak D, Agt-Rickauer H, Hentschel C, Filipowska A, Sack H	2016	Lecture Notes In Business Information Processing	2	Germany	Quantitative analysis of art market using ontologies, named entity recognition and machine learning: A case study	Conference Paper	Alternative investment; Art market; Digital humanities; Information retrieval; Linked data; Machine learning; Semantic web
64.	Wenjing X, Cai Z	2023	Soft Computing	1	China	Assessing the best art design based on artificial intelligence and machine learning using GTMA	Article	Art design; Artificial intelligence; Emotions; Machine learning; Sentiments
65.	Chen A, Jesus R, Vilarigues M	2023	Sn Computer Science	1	Portugal	Identification and Visualization of Pure and Mixed Paint Pigments in Heritage Artwork Using Machine Learning Algorithms	Article	Deep neural networks; Hyperspectral imaging; Painting reconstruction; Pigment identification; Pigment unmixing; Visualization

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
66.	Srinivasa Desikan B, Shimao H, Miton H	2022	Entropy	1	United States	WikiArtVectors: Style and Color Representations of Artworks for Cultural Analysis via Information Theoretic Measures	Article	analysis framework; art history; color representations; cultural analysis; dataset; deep learning; information theory; style extraction
67.	Wang F, Geng S, Zhang D, Zhou M, Nian W, Li L	2022	Proceedings - 2022 International Conference On Cyberworlds, Cw 2022	1	China	A Fine-grained Classification Method of Thangka Image Based on SENet	Conference Paper	Fine-grained classification; Intangible cultural heritage; SENet; Thangka image; Training strategy
68.	Charitha PL, Mydhili M, Khyathi N, Pavithra P, Anuradha G	2022	Lecture Notes In Networks And Systems	1	India	Detection of Weed Plants Using Image Processing and Deep Learning Techniques	Conference Paper	Classification; Crop plants; Image processing; Multispectral images; Weed plants; YoloV3
69.	Li Z, Lin S, Peng Y	2021	Proceedings Of 2021 Ieee International Conference On Data Science And Computer Application, Icdsca 2021	1	China	Chinese Painting Style Transfer System Based on Machine Learning	Conference Paper	artificial intelligence; Chinese style; image processing; machine learning; style transfer
70.	Sun X, Qin J	2021	Advances In Intelligent Systems And Computing	1	China	Deep Learning-Based Creative Intention Understanding and Color Suggestions for Illustration	Conference Paper	Color suggestion; Deep learning; Human machine cooperation; Illustration

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
71.	Goenaga MA	2020	Ausart	1	Spain	A critique of contemporary artificial intelligence art: Who is Edmond de Belamy?	Article	ART; ARTIFICIAL INTELLIGENCE; BLOCKCHAIN; COMPUTATIONAL AESTHETICS; COMPUTER SCIENCE; CREATIVITY; DEEP LEARNING; GANISM; MARKET; NEURAL NETWORKS; NEUROSCIENCE
72.	Sizyakin R, Cornelis B, Meeus L, Voronin V, Pižurica A	2020	Proceedings Of Spie - The International Society For Optical Engineering	1	Rusia	A two-stream neural network architecture for the detection and analysis of cracks in panel paintings	Conference Paper	Convolutional neural network (CNN); Crack detection; Fully connected neural network; Multimodal data; Panel paintings
73.	Guo B, Hao P	2020	2020 Ieee International Conference On Multimedia And Expo Workshops, Icmew 2020	1	United Kingdom	Analysis of artistic styles in oil painting using deep-learning features	Conference Paper	Art styles; Dimensionality reduction; Distance Maps; Gram Matrix
74.	Dong W	2020	Proceedings - 2020 International Conference On Computers, Information Processing And Advanced Education, Cipae 2020	1	China	Research on the Method of Image Recognition Based on Edge Calculation in Landscape Painting	Conference Paper	Authenticity identification; Data fusion; Edge detection; Feature extraction; Landscape painting

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
75.	Zhang X, Luo L	2020	2020 International Conference On Artificial Intelligence In Information And Communication, Icaiic 2020	1	China	Using CNN to identify map patches based on high-resolution data	Conference Paper	CNN; Cultivated land extraction; GF-2; Machine learning; Water extract
76.	Ceroni A, Ma C, Ewerth R	2018	Icmr 2018 - Proceedings Of The 2018 Acm International Conference On Multimedia Retrieval	1	Germany	Mining exoticism from visual content with fusion-based deep neural networks	Conference Paper	Benchmark; Exoticism; Human computation; Image classification
77.	Karnewar A, Kanawaday A, Sawant C, Gupta Y	2017	Acm International Conference Proceeding Series	1	India	Classification of abstract images using machine learning	Conference Paper	Abstract art; Artificial intelligence; Convolutional Neural Network; Deep learning; Feature extraction; Image processing; Machine learning; Neural networks
78.	Esposito F	2013	Doceng 2013 - Proceedings Of The 2013 Acm Symposium On Document Engineering	1	Italy	Symbolic machine learning methods for historical document processing	Conference Paper	concept learning methods; incremental learning; inductive logic programming; semantic processing
79.	Mengyao C, Yu T	2023	Soft Computing	0	China	Intelligent product art design based on smart equipment and machine learning algorithm: practice effect and trend analysis	Article	Art design; Intellectualization; Machine learning; Product art

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
80.	Allahloh AS, Sarfraz M, Ghaleb AM, Al-Shamma'a AA, Hussein Farh HM, Al-Shaalan AM	2023	Sustainability	0	Saudi Arabia	Revolutionizing IC Genset Operations with IIoT and AI: A Study on Fuel Savings and Predictive Maintenance	Article	artificial intelligence; CAT genset; electronic control module; fuel efficiency; Industrial Internet of Things; machine learning; Modbus RTU; predictive maintenance; radar transmitter; standalone IIoT platform
81.	Li H, Fang J, Jia Y, Ji L, Chen X, Wang N	2023	Electronics	0	China	Thangka Sketch Colorization Based on Multi-Level Adaptive-Instance-Normalized Color Fusion and Skip Connection Attention	Article	attention; machine learning; Thangka
82.	Huang Y	2023	Proceedings Of Spie - The International Society For Optical Engineering	0	China	A method of generating abstract ink paintings based on machine learning	Conference Paper	Abstract ink painting; Generative art; Image generation; Machine learning
83.	Varshney N, Kumar G, Kumar A, Pandey SK, Singh T, Singh KU	2023	Proceedings - 2023 12th Ieee International Conference On Communication Systems And Network Technologies, Csnt 2023	0	India	AI-Enable Generating Human Faces using Deep Learning	Conference Paper	component; formatting; insert (key words); style; styling

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
84.	Cascone L, Nappi M, Narducci F, Russo SL	2023	Journal Of Ambient Intelligence And Humanized Computing	0	Italy	Classification of fragments: recognition of artistic style	Article	Classification; Image fragmentation; Image processing; Image reconstruction; Machine learning
85.	Yu R, Tan B	2023	Lecture Notes In Computer Science (including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	0	China	Construction of Color Network Model of Folk Painting Based on Machine Learning	Conference Paper	Color matching; Folk painting; Machine learning; Network model; Painting color
86.	Seal S, Yang HB, Trapotsi MA, Singh S, Carreras-Puigvert J, Spjuth O, Bender A	2023	Journal Of Cheminformatics	0	Sweden	Merging bioactivity predictions from cell morphology and chemical fingerprint models using similarity to training data	Article	Machine learning; Cell Painting; Structure; Toxicity; Bioactivity; Applicability domain
87.	Fan H-T, Xiao G, Arinez J, Coulthard M	2022	Manufacturing Letters	0	United States	A Case Study on First Time Quality Feature Investigation for an Automotive Paint Shop	Article	artificial intelligence; automotive paint shop; feature investigation; Machine learning; manufacturing

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88.	Hu B	2022	International Journal Of Humanoid Robotics	0	China	Analysis of Art Therapy for Children with Autism by Using the Implemented Artificial Intelligence System	Article	art therapy; artificial intelligence; autism; Children
89.	Gengenbach T, Schoch K	2022	Journal Of Science And Technology Of The Arts	0	Germany	ARTIFICIAL INTELLIGENCE RATERS: NEURAL NETWORKS FOR RATING PICTORIAL EXPRESSION	Article	Artificial intelligence raters; Machine learning; Neural nets; Pictorial expression; Visual art
90.	Choi J-I, Kim S-K, Kang S-J	2022	Cmes - Computer Modeling In Engineering And Sciences	0	Korea	Image Translation Method for Game Character Sprite Drawing	Article	Body segmentation; Deep learning; Generative adversarial network; Pose estimation; Sprite generation
91.	Xu Y, Nazir S	2022	Journal Of Software: Evolution And Process	0	Pakistan	Ranking the art design and applications of artificial intelligence and machine learning	Article	art design; artificial intelligence; machine learning; ranking
92.	Sierotowicz M, Brusamento D, Schirrmeister B, Connan M, Bornmann J, Gonzalez-Vargas J, Castellini C	2022	Frontiers In Robotics And Ai	0	Germany	Unobtrusive, natural support control of an adaptive industrial exoskeleton using force myography	Article	adaptive support; exoskeletons; force myography; human–machine interaction; machine learning

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
93.	Li H, Zhang Z	2022	Proceedings - 2022 3rd International Conference On Electronic Communication And Artificial Intelligence, Iwecai 2022	0	China	A Study of Unsupervised Networks Based on the Network Prior for the Image Inpainting	Conference Paper	control variable method; in painting; neural network; Skip connection; Unet
94.	Machado M, Lima G, Soares E, Nascimento V, Brandao R, Moreno M	2022	Ceur Workshop Proceedings	0	Brazil	An Extensible Approach for Query-Driven Multimodal Knowledge Graph Completion	Conference Paper	Hyperknowledge; Hyperlinked Knowledge Graph; Knowledge Graph Completion; Multimodal data
95.	Avellino F, Grieco R, Piedimonte L, Ressegotti D, Zangari G, Ferraiuolo A, Orselli S, Paluan M	2022	Ifac-papersonline	0	Italy	Application of Big Data technologies in downstream steel process	Conference Paper	Big Data; Lambda; Message Broker; real-time processing; sensor equipment
96.	Huang K, Jiang J	2022	Communications In Computer And Information Science	0	China	Application of Machine Learning Algorithm in Art Field – Taking Oil Painting as an Example	Conference Paper	AnimeGAN; CartoonGAN; Generative confrontation network; Image style transfer
97.	Ferguson EL, Castillo M, Kazzaz A, Dunner TF	2022	Society Of Petroleum Engineers - Adipec 2022	0	-	Case Study on the Impacts of an Automated Condition Assessment System Deployed Across Offshore Production Facilities	Conference Paper	Efficiency; Fabric Maintenance; Inspection; Machine Learning; Prioritization

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98.	Su H, Huang J, Ito Y, Nakano K	2022	Proceedings - 2022 10th International Symposium On Computing And Networking Workshops, Candarw 2022	0	Japan	ConvUNeXt: A Lightweight Convolutional Neural Network for Watercolor Image Translation	Conference Paper	CNN; conditional GAN; deep learning; image-to-image translation; watercolor art
99.	Lu J-L, Ochiai Y	2022	Lecture Notes In Computer Science (including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	0	Japan	Customizable Text-to-Image Modeling by Contrastive Learning on Adjustable Word-Visual Pairs	Conference Paper	AI visual content creation; Contrastive learning; Text-to-image model
100.	Yang F, Caballero JM, Juanatas RA	2022	Icbir 2022 - 2022 7th International Conference On Business And Industrial Research, Proceedings	0	Philippines	Designing of Chinese Ancient Poetry App Based on iOS Platform Augmented Reality and Machine Learning	Conference Paper	app; augmented reality; culture; machine learning; poetry
101.	Yang K	2022	Proceedings - 2022 2nd International Conference On Networking, Communications And Information Technology, Netcit 2022	0	China	Landscape Art Image Style Reconstruction Algorithm Based on Machine Learning	Conference Paper	Image Style Reconstruction Algorithms; Landscape; Machine Learning
102.	Cheng Y	2022	Acm International Conference Proceeding Series	0	China	Laplacian Pyramid Network for Transferring Picture into Van Gogh's Style	Conference Paper	Computer Vision; Lapstyle; Machine Learning; Style transfer; Van Gogh

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
103.	Ragot S	2022	World Patent Information	0	Switzerland	Measuring the originality of intellectual property assets based on estimated inter-asset distances	Article	Originality; Unsupervised machine learning; Copyright; Design rights; Intellectual property
104.	Kher D, Passi K	2022	International Conference On Web Information Systems And Technologies, Webist - Proceedings	0	Canada	Multi-label Emotion Classification using Machine Learning and Deep Learning Methods	Conference Paper	Deep Learning; Ensemble Methods; GRU based RNN; KNN; Machine Learning; Multi-label Emotion Classification; Naïve Bayes; One-way ANOVA; Python; Random Forest; SVM; Twitter
105.	Ciortan IM, Arteaga Y, George S, Hardeberg JY	2022	Communications In Computer And Information Science	0	France	Multi-scale Painter Classification	Conference Paper	Art attribution; Machine learning; Multi-scale classification; Pyramid of histogram of oriented gradients; Residual neural network
106.	Wang L	2022	Proceedings Of Spie - The International Society For Optical Engineering	0	China	Research on authenticity identification of Chinese painting based on computer technology	Conference Paper	Chinese painting; computer technology; computer vision technology; identification

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107.	Vadicherla D, Gadicha V	2022	Lecture Notes In Electrical Engineering	0	India	Supervised Machine Learning Approach for Crack Detection in Digital Images	Conference Paper	Classification of images; Crack detection; Supervised machine learning; Support vector machine
108.	Gupta S, Ziemons J, Trengove E	2022	Iclp 2022 - 36th International Conference On Lightning Protection	0	Africa	Using Machine Learning to Identify Lightning in Paintings	Conference Paper	art; lightning; machine learning
109.	Sizyakin R, Voronin V, Zelensky A, Pižurica A	2022	Journal Of Electronic Imaging	0	Rusia	Virtual restoration of paintings using adaptive adversarial neural network	Article	adaptive adversarial neural networks; convolutional neural network; crack detection; deep-learning; segmentation; U-Net; virtual restoration of paintings
110.	Yang H, Yang H	2021	Entropy	0	China	Evolution of entropy in art painting based on the wavelet transform	Article	Art history; Entropy; Information theory; Machine learning; Paintings; Wavelet transform

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
111.	Tan M, Xu S, Zhang S, Chen Q	2021	Journal Of Image And Graphics	0	China	A review on deep adversarial visual generation [深度对抗视觉生成综述]	Review	3D-depth image generation; Controllable generation; Deep learning; Generative adversarial networks (GANs); Image generation; Style transfer; Video generation; Visual generation
112.	Hebert L, Eddy E, Harrington W, Marchand L, D'Eon J, Oore S	2021	Icmi 2021 Companion - Companion Publication Of The 2021 International Conference On Multimodal Interaction	0	Canada	ArtBeat Deep Convolutional Networks for Emotional Inference to Enhance Art with Music	Conference Paper	affective analysis; computational creativity
113.	Sharma HK, Choudhury T, Mohanty SN, Swagatika S, Swain S	2021	Ceur Workshop Proceedings	0	India	Deep Learning based approach for Photographs and Painting Classification using CNN Model	Conference Paper	Classification; CNN; Deep Learning; Image Processing; Machine Learning
114.	Mocanu A-A, Iftene A	2021	Proceedings - 2021 23rd International Symposium On Symbolic And Numeric Algorithms For Scientific Computing, Synasc 2021	0	Romania	How the Events in the Life of Painters Influence the Colors of their Paintings	Conference Paper	Clustering; Gaussian Mixture Model; K-means; Sentiment analysis

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
115.	Chen A, Jesus R, Vilarigues M	2021	Lecture Notes In Computer Science (including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	0	Portugal	Identification of Pure Painting Pigment Using Machine Learning Algorithms	Conference Paper	Artificial intelligence; Hyperspectral imaging; Machine learning; Neural network; Painting reconstruction; Pigment identification; Pigment unmixing; Restoration; Visualization
116.	Popov S, Kavkler K, Dzeroski S	2021	2021 44th International Convention On Information, Communication And Electronic Technology, Mipro 2021 - Proceedings	0	Slovenia	Using Machine Learning to Identify Factors Contributing to Mould in the Celje Ceiling Painting	Conference Paper	classification; feature ranking; historic art conservation; machine learning
117.	Sera T, Izukura S, Hashimoto I, Motegi T, Motohashi Y	2020	Acm International Conference Proceeding Series	0	Japan	A case study of Food Production Using Artificial Intelligence	Conference Paper	Artificial Intelligence; Food production; Recipe generation
118.	Jainulabudeen SAK, Shalma H, Shankar SG, Anuradha D, Soniya K	2020	Advances In Parallel Computing	0	India	A Novel Technique to Regenerate Sculpture Using Generative Adversarial Network	Article	Artificial Intelligence; DCGAN model; Machine Learning; Sculpture
119.	Karoly AI, Takacs M, Galambos P	2019	Proceedings Of The International Joint Conference On Neural Networks	0	Hungary	OCSVM-based Evaluation Method for Generative Neural Networks	Conference Paper	Generative Adversarial Networks; Image Synthesis; One-Class Support Vector Machine

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
120.	Raza A, Abdullah M, Hassan W, Abdulali A, Talhan A, Jeon S	2019	Lecture Notes In Electrical Engineering	0	Korea	Painting Skill Transfer Through Haptic Channel	Conference Paper	Deep learning; Haptic guidance; Haptic painting; Haptic rendering; Painting skill
121.	Zaheer MZ, Astrid M, Lee S-I, Shin HC	2018	International Conference On Control, Automation And Systems	0	Korea	Ensemble grid formation to detect potential anomalous regions using context encoders	Conference Paper	Anomaly Detection; Image Reconstruction; Semantic Inpainting; Surveillance Robot
122.	Malehmir R, Coram C, Firbank D, Palsat B, Palesch D	2018	Transportation Association Of Canada Conference - Innovation And Technology: Evolving Transportation, Tac 2018	0	Canada	Machine learning powered roadside asset extraction using LiDAR	Conference Paper	LiDAR; Line painting marker; Machine learning; Traffic signs
123.	Lee E-M, Joo M-K	2017	Journal Of Theoretical And Applied Information Technology	0	Korea	A relative evaluation of aesthetic value for contemporary abstract art created by computer creativity	Article	Abstract art; Aesthetic value; Artificial intelligence; Computer creativity; Neural networks
124.	Montagnuolo M, Messina A, Bidotti N, Platter P, Bosca A	2017	Proceedings - 2017 Ieee International Conference On Big Data, Big Data 2017	0	Italy	Real time semantic enrichment of broadcast content in the big data age	Conference Paper	broadcast archives; linked data; semantic tagging; visual search

No.	Authors	Year	Journal	Citations	Country	Title	Doc type	Keywords
125.	Xie N, Ren M, Yang W, Yang Y, Shen HT	2017	Lecture Notes In Computer Science (including Subseries Lecture Notes In Artificial Intelligence And Lecture Notes In Bioinformatics)	0	China	WebPainter: Collaborative Stroke-Based Rendering Through HTML5 and WebGL	Conference Paper	Artistic stylization; CSCW; SBR; WebGL
126.	Florea L, Florea C, Badea M	2016	Ieee International Conference On Communications	0	Romania	Recognizing surreal compositions in digitized paintings	Conference Paper	GIST; Painting classification; Random Forest; Realism; Surrealism
127.	Qu D, Luo Y, Tan W	2011	Proceedings - 2011 Ieee International Conference On Computer Science And Automation Engineering, Csae 2011	0	China	An improved painting-based transfer function design approach with CUDA-acceleration	Conference Paper	Artificial Neutral Network; CUDA; Painting-Based Interface; Statistics; Transfer Function
128.	Yu K, Yu S, Tresp V	2005	Proceedings - 2005 Ieee Computer Society Conference On Computer Vision And Pattern Recognition, Cvpr 2005	0	Germany	Multi-output regularized projection	Conference Paper	Abstract art; Aesthetic value; Artificial intelligence; Computer creativity; Neural networks

Author contributions JV, GGP, and VGP. conceived and designed the study. AV-A, JA-D, and RT contributed to data collection and analysis. All authors were involved in the interpretation of the results. JV and GGP drafted the manuscript, while VGP, AV-A, JA-D, and RT provided critical revisions. All authors reviewed and approved the final version of the manuscript for publication.

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Data availability The data may be provided free of charge to interested readers by requesting the correspondence author's email.

Declarations

Competing interest The authors declare no competing interests.

References

Achlioptas P, Ovsjanikov M, Haydarov K, Elhoseiny M, Guibas LJ (2021) ArtEmis: affective language for visual art. In: Proceedings of the IEEE Computer Society Conference on Computer Vision and PatternRecognition https://doi.org/10.1109/cvpr46437.2021.01140

Alameda-Pineda X, Ricci E, Yan Y, Sebe N (2016) Recognizing emotions from abstract paintings using non-linear matrix completion. In: Proceedings of the IEEE Computer Society Conference on Computer Vision and Pattern Recognition. https://doi.org/10.1109/cvpr.2016.566

Allahloh AS, Sarfraz M, Ghaleb AM, Al-Shamma'a AA, Farh H, Al-Shaalan AM (2023) Revolutionizing IC genset operations with IIoT and AI: a study on fuel savings and predictive maintenance. Sustainability 15:8808. https://doi.org/10.3390/su15118808

Belhi A, Bouras A, Foufou S (2018) Leveraging known data for missing label prediction in cultural heritage context. Appl Sci 8(10):1768. https://doi.org/10.3390/app8101768

Bidgoli A, De Guevara ML, Hsiung C, Oh J, Kang E (2020) Artistic style in robotic painting; a machine learning approach to learning brushstroke from human artists. In: 29th IEEE International Conference on Robot and Human Interactive Communication, RO-MAN 2020. https://doi.org/10.1109/ro-man47096.2020.9223533

Boloor A, Garimella K, He X, Gill C, Vorobeychik Y, Zhang X (2020) Attacking Vi-sion-based perception in end-to-end autonomous driving models. J Syst Architect 110:101766. https://doi.org/10.1016/j.sysarc.2020.101766

Califano A, Foti P, Berto F, Baiesi M, Bertolin C (2022) Predicting damage evolution in panel paintings with machine learning. Procedia Struct Integr 41:145–157. https://doi.org/10.1016/j.prostr.2022.05.017

Cascone L, Nappi M, Narducci F, Russo SL (2023) Classification of fragments: recognition of artistic style. J Ambient Intell Humaniz Comput 14:4087–4097. https://doi.org/10.1007/s12652-022-04472-x

Chen A, Jesus R, Vilarigues M (2022) Identification and visualization of pure and mixed Paint pigments in heritage artwork using machine learning algorithms. SN Comput Sci 4:115. https://doi.org/10.1007/s42979-022-01529-8

Cucci C, Barucci A, Stefani L, Picollo M, Jiménez-Garnica R, Fuster-Lopez L (2021) Reflectance hyperspectral data processing on a set of picasso paintings: which algorithm provides what? A comparative analysis of multivariate, statistical and artificial intel-ligence methods. In R. Groves & H. Liang (Eds.), Proceedings of the Optics for Arts, Architecture, and Archaeology VIII. p. 1

Culjak M, Mikus B, Jez K, Hadjic S (2011) Classification of art paintings by genre. In: International Convention on Information and Communication Technology, Electronics and Microelectronics, pp. 1634–1639. https://ieeexplore.ieee.org/document/5967323/

Dobbs T, Benedict A, Ras Z (2022) Jumping into the artistic deep end: building the Cata-Logue Raisonné. AI Soc 37:873–889. https://doi.org/10.1007/s00146-021-01370-2

Durieux V, Gevenois PA (2010) Bibliometric indicators: quality measurements of scientific publication. Radiology 255:342–351. https://doi.org/10.1148/radiol.09090626

Fails JA, Olsen DR (2003a) Interactive machine learning. In: Proceedings of the 8th International Conference on Intelligent User Interfaces; ACM, pp. 39–45

Fails JA, Olsen DR (2003b) Interactive machine learning. In: Proceedings of the Proceedings of the 8th International Conference on Intelligent User Interfaces; ACM, pp. 39–45

Fails J, Olsen D (2003c) A design tool for camera-based interaction. In: Proceedings of the SIGCHI Conference on Human Factors in Computing Systems; ACM, 449–456
Falomir Z, Museros L, Sanz I, Abril LG (2018) Categorizing paintings in art styles based on qualitative color descriptors, quantitative global features and machine learning (QArt-Learn). Expert Syst Appl 97:83–94. https://doi.org/10.1016/j.eswa.2017.11.056
Fan H-T, Xiao G, Arinez J, Coulthard M (2022) A case study on first time quality feature investigation for an automotive paint shop. Manuf Lett 33:919–926. https://doi.org/10.1016/j.mfglet.2022.07.112
Folego G, Gomes O, Rocha A (2016) From impressionism to expressionism: automatically identifying Van Gogh's paintings. In: Proceedings-International Conference on Image Processing, ICIP https://doi.org/10.1109/icip.2016.7532335
Gengenbach T, Kerstin S (2022) Artificial intelligence raters. neural networks for rating pictorial expression. J Sci Technol Arts 14:49–71
Gülzow JM, Paetzold P, Deussen O (2020) Recent developments regarding painting robots for research in automatic painting, artificial creativity, and machine learning. Appl Sci 10:3396. https://doi.org/10.3390/app10103396
Hu B (2022) Analysis of art therapy for children with autism by using the implemented artificial intelligence system. Int J Humanoid Rob. https://doi.org/10.1142/S0219843622400023
Irfan MT, Stork DG (2009) Multiple visual features for the computer authentication of Jackson Pollock's drip paintings: beyond box counting and fractals. Proceedings Of SPIE. https://doi.org/10.1117/12.806245
Jboor NH, Belhi A, Al-Ali AK, Bouras A, Jaoua A (2019) Towards an inpainting framework for visual cultural heritage. In: Proceedings of the 2019 IEEE Jordan Interna-Tional Joint Conference on Electrical Engineering and Information Technology (JEEIT); IEEE, pp. 602–607
Jeong JH, Woo JH, Park J (2020) Machine learning methodology for management of shipbuilding master data. Int J Naval Archit Ocean Eng 12:428–439. https://doi.org/10.1016/j.ijnaoe.2020.03.005
Knippenberg E, Jensen N, Constas M (2019) Quantifying household resilience with high frequency data: temporal dynamics and methodological options. World Dev 121:1–15. https://doi.org/10.1016/j.worlddev.2019.04.010
Kogou S, Lee L, Shahtahmassebi G, Liang H (2020) A new approach to the interpretation of XRF spectral imaging data using neural networks. X-Ray Spectrom 50(4):310–319. https://doi.org/10.1002/xrs.3188
Kumar M, Sharma S, Chaudhary D, Prakash S (2021) Image recognition using artificial intelligence. In: Proceedings of the 2021 International Conference on Advance Computing and Innovative Technologies in Engineering (ICACITE); IEEE, pp. 760–763
Lc R (2023) Human enough: a space for reconstructions of AI visions in speculative climate futures. Creat Cognit. https://doi.org/10.1145/3591196.3593341
Li C, Chen T (2009) Aesthetic visual quality assessment of paintings. IEEE J Sel Top Signal Process 3:236–252. https://doi.org/10.1109/JSTSP.2009.2015077
Li H, Zhang Z (2022) A study of unsupervised networks based on the network prior for the image inpainting. In: Proceedings of the 2022 3rd International Conference on Electronic CommuInication and Artificial Intelligence (IWECAI); IEEE: pp. 07–110
Liu Y, Qin Z, Wan T, Luo Z (2018) Auto-painter: cartoon image generation from sketch by using conditional wasserstein generative adversarial networks. Neurocomputing 311:78–87. https://doi.org/10.1016/j.neucom.2018.05.045
Lu Y, Guo C, Dai X, Wang F-Y (2021) Image captioning on fine art paintings via virtual paintings. In: Proceedings of the 2021 IEEE 1st International Conference on Digital Twins and Parallel Intelligence. DTPI, pp. 156–159
Lürig MD, Donoughe S, Svensson EI, Porto A, Tsuboi M (2021) Computer vision, machine learning, and the promise of phenomics in ecology and evolutionary biology. Front Ecol Evol. https://doi.org/10.3389/fevo.2021.64277
Mao W (2022) Video analysis of intelligent teaching based on machine learning and virtual reality technology. Neural Comput Appl 34:6603–6614. https://doi.org/10.1007/s00521-021-06072-w
Mengyao C, Yu T (2023) Intelligent product art design based on smart equipment and ma-chine learning algorithm: practice effect and trend analysis. Soft Comput 27:8449–8458. https://doi.org/10.1007/s00500-023-08146-4
Mondal B (2019) Artificial intelligence: state of the art. En Intell Syst Ref Libr. https://doi.org/10.1007/978-3-030-32644-9_32
Orduña-Malea E, Costas R (2021) Link-based approach to study scientific software usage: the case of VOSviewer. Scientometrics 126:8153–8186. https://doi.org/10.1007/s11192-021-04082-y

Page MJ, McKenzie JE, Bossuyt PM, Boutron I, Hoffmann TC, Mulrow CD, Shamseer L, Tetzlaff JM, Akl EA, Brennan SE (2021) The PRISMA 2020 Statement: an updated guideline for reporting systematic reviews. Int J Surg 88:105906. https://doi.org/10.1016/j.ijsu.2021.105906

Pedraza-Navarro I, Sánchez-Serrano S (2022) Análisis De Las Publicaciones presentes En WoS Y Scopus. Posibilidades De Búsqueda Para Evitar Literatura Fugitiva En Las Revisiones Sistemáticas. Revista Interuniversitaria De Investigación en Tecnología Educativa 2022:41–61. https://doi.org/10.6018/riite.548361

Polatkan G, Jafarpour S, Brasoveanu A, Hughes SM, Daubechies I (2009) Detection of forgery in paintings using supervised learning. In: Proceedings-International Conference on Image Processing, ICIP https://doi.org/10.1109/icip.2009.5413338

Ragot S (2022) Measuring the originality of intellectual property assets based on estimated inter-asset distances. World Patent Inf 69:102106. https://doi.org/10.1016/j.wpi.2022.102106

Safra L, Chevallier C, Grèzes J, Baumard N (2020) Tracking historical changes in perceived trustworthiness in Western Europe using machine learning analyses of facial cues in paintings. Nat Commun. https://doi.org/10.1038/s41467-020-18566-7

Sánchez Santana P, Roman-Rangel E (2021) Quantifying visual similarity for artistic styles. In: Roman-Rangel E, Kuri-Morales ÁF, Martínez-Trinidad JF, Carrasco-Ochoa JA, Olvera-López JA (eds) Pattern recognition. MCPR 2021. Lecture Notes in Computer Science, vol. 12725. Springer, Cham. https://doi.org/10.1007/978-3-030-77004-4_18

Sanhudo L, Calvetti D, Martins JP, Ramos NMM, Mêda P, Gonçalves MC, Sousa H (2021) Activity classification using accelerometers and machine learning for com-plex construction worker activities. J Building Eng 35:102001. https://doi.org/10.1016/j.jobe.2020.102001

Spee BTM, Mikuni J, Leder H, Scharnowski F, Pelowski M, Steyrl D (2023) Machine learning revealed symbolism, emotionality, and imaginativeness as primary predictors of creativity evaluations of Western art paintings. Sci Rep. https://doi.org/10.1038/s41598-023-39865-1

Srinivasa Desikan B, Shimao H, Miton H (2022) WikiArtVectors: style and color repre-sentations of artworks for cultural analysis via information theoretic measures. Entropy 24:1175. https://doi.org/10.3390/e24091175

Sun X, Qin J (2021) Deep learning-based creative intention understanding and color suggestions for illustration. In: Ahram T (eds) Advances in Artificial Intelligence, Software and Systems Engineering. AHFE 2020. Advances in Intelligent Systems and Computing, vol 1213. Springer, Cham. https://doi.org/10.1007/978-3-030-51328-3_14

Tian T, Nan F (2022) A multitask convolutional neural network for artwork appreciation. Mobile Information Systems. https://doi.org/10.1155/2022/8804711

Tzeng F-Y, Lum EB (2005) Kwan-Liu Ma An intelligent system approach to higher dimensional classification of volume data. IEEE Trans Vis Comput Graph 11:273–284. https://doi.org/10.1109/TVCG.2005.38

Vadicherla D, Gadicha V (2022) Supervised machine learning approach for crack detection in digital images. In: Tomar A, Malik H, Kumar P, Iqbal A (eds) Proceedings of 3rd International Conference on Machine Learning, Advances in Computing, Renewable Energy and Communication. Lecture Notes in Electrical Engineering, vol 915. Springer, Singapore. https://doi.org/10.1007/978-981-19-2828-4_21

Van Der Maaten L, Erdmann RG (2015) Automatic thread-level canvas analysis: a machine-learning approach to analyzing the canvas of paintings. IEEE Signal Process Mag 32(4):38–45. https://doi.org/10.1109/msp.2015.2407091

Wenjing X, Cai Z (2023) Assessing the best art design based on artificial intelligence and machine learning using GTMA. Soft Comput 27:149–156. https://doi.org/10.1007/s00500-022-07555-1

Xu Y, Nazir S (2022) Ranking the art design and applications of artificial intelligence and machine learning. J Softw Evol Process. https://doi.org/10.1002/smr.2486

Yu T, Lin C, Zhang S, Wang C, Ding X, An H, Liu X, Qu T, Wan L, You S (2022) Artificial intelligence for Dunhuang cultural heritage protection: the project and the dataset. Int J Comput Vis 130:2646–2673. https://doi.org/10.1007/s11263-022-01665-x

Zhang J, Duan Y, Gu X (2021) Research on emotion analysis of Chinese Literati painting images based on deep learning. Front Psychol. https://doi.org/10.3389/fpsyg.2021.723325

Zhao W, Zhou D, Qiu X, Jiang W (2021) How to represent paintings: a painting classification using artistic comments. Sensors. https://doi.org/10.3390/s21061940

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