Hot Spots and Frontiers in Embroidery Research: A Visualization Analysis via CiteSpace Based on WOS Databases (2010–2022)

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Abstract—Embroidery and weaving techniques are part of the cultural heritage and are the fruit of human civilisation. With the improvement of the technical level of the embroidery machine manufacturing industry, the global embroidery Market in 2022 has reached 7.35 billion US dollars, growing by 10.18% year-on-year, making it an economic research field. In this paper, we used WOS databases to search core papers and CiteSpace, a knowledge graph analysis tool, to determine the current status and trends of research in embroidery from 2010 to 2022. Based on the screened articles, the number of publications, research authors and institutions, keyword co-occurrences, and changes in highlighted words were analyzed in this study. The results showed that China, the United States, and the United Kingdom are the leading researchers in embroidery. Chinese scholars have had an interdisciplinary trend recently and have begun to publish abroad actively. The results of these studies have provided an opportunity for scholars in the field of embroidery to study the cultural connotation and innovative design of embroidery. These results point out the direction for scholars in the field of embroidery research and innovation, identify the shortcomings of each in the current situation of research in China and overseas, find a sustainable path for the development of embroidery craft, and promote the exchange and mutual appreciation of civilizations.

Index Terms—Embroidery, bibliometrics, comparative mapping analysis, cultural exchange

I. INTRODUCTION

Using an embroidery needle to draw coloured threads (silk, velvet, or thread) and embroidering the cloth according to a planned pattern, therefore generating a pattern or text with the embroidered marks, is the process that constitutes embroidery. In the context of globalisation, it is possible to make use of it as a medium to cultivate a national visual image and to disseminate national culture. The UNESCO Intangible Cultural Heritage List now includes the "Traditional Dyeing, Weaving, and Embroidery Techniques of the Li People," as well as the "Al Talli" of the United Arab Emirates and the cultural traditions of many other nations. Research on needlework has been going on for a very long time in China since the country has such a huge geographical region and so many different ethnic groups. Although the development of embroidery in China has been described in terms of stitches by dynasty, and the spiritual culture of traditional Chinese embroidery has been analysed from the perspective of social and cultural history [1], the current review articles in the field of embroidery are generally older [2]. They still need to be categorised in terms of academic research. With the exchange of cultures and the emergence of machine embroidery, the variety of embroidery has become complex and diverse. Research methods have shifted from fieldwork methods and iconographic methods to integration with big data and artificial intelligence. The use of robotics and artificial intelligence in embroidery can greatly improve production efficiency while simultaneously helping in the transmission of embroidery and artistic innovation [3]. Moreover, despite the significance of embroidery in traditional arts and crafts, no academic has yet done a review of developments in this field using the CiteSpace methodology to understand the research trends. This is despite the fact that embroidery is an important part of traditional arts and crafts. The most recent knowledge structure in embroidery has to be visualised and analysed, and the most important research areas and frontiers need to be determined.

The CiteSpace programme was used in this investigation to carry out a bibliometric examination of the critical literature that was published in the needlework sector between the years 2010 to 2022. It does this by comparing and analysing the number of articles, research authors and institutions, hot research areas where keywords co-occur, and cutting-edge research themes that highlight word changes. The purpose of this is to sort out the research hotspots in the embroidery field and to assist academics in locating their own weaknesses and capitalising on one another's strengths.

II. DATA SOURCES AND RESEARCH METHODOLOGY

A. Data Collection

We searched the main database of WOS (Web of Science) using the logical connection "or," limiting our search to the time period from 2010 to 2022. As topic keywords, we used "embroidery," "needlework," and "drawnwork," and we looked for references to "laces." After filtering out a huge number of medical and insect field articles, correspondence, and duplicate data, the search yielded a total of 3583 documents, of which only 610 were academic publications that were relevant to the topic.

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B. Research Methodology

CiteSpace 6.1.R3, a representative analysis tool in bibliometrics developed by Professor Chaomei Chen, was chosen as the knowledge mapping analysis tool for this study. CiteSpace 6.1.R3 is based on Kuhn's theory of scientific development patterns, Derek John de Solla Price's theory of scientific frontiers, the institutional hole theory of social network analysis, the information foraging theory of scientific communication, as well as the theory of discrete and reorganised knowledge units. The development is finished off with the theory, which has the potential to disclose the dynamic growth pattern of the knowledge domain and provide a reference that is both useful and practical for study within the discipline. The primary parameters are adjusted as shown below.

1) Time Slicing: January 2010-December 2022, time slices for each year.
2) Node Types: Author, Issuing Institution, Issuing Country, Keywords.
3) Links: Strength is "Cosine," Scope is "Within Slices."
4) Selection Criteria: Pruning is set to "Pathfinder," "Pruning sliced networks," Visualization is Set to "Cluster View - Static," and "Merged Network."

III. Analysis of Published Literature

A. Analysis of Published Literature

Fig. 1 displays the number of publications that have been published in the subject of embroidery study over the course of the last twelve years. This figure may directly indicate the active level of the field as well as its development trend in various time periods. As can be seen in Figure 1, the number of articles published in the field of embroidery in foreign countries has generally shown an increasing trend between the years of 2010 and 2022, with a rapid growth of 242.1%. This growth can be directly attributed to the rise in the number of researchers publishing in this area.

According to the findings of the study, the countries of China (160), the United States (58), the United Kingdom (47), Russia (25), and Spain (19) are the top five countries in terms of the number of papers written in the English language that are related to needlework research.

After China proposed in the Outline of the 13th Five-Year Plan for Economic and Social Development of the People's Republic of China to strengthen the research, excavation, and innovative development of excellent Chinese traditional culture and to inherit and revitalise national folk culture, the number of articles published in the field of embroidery began to increase sharply in 2016. This was after China proposed in 2016 to strengthen the research, excavation, and innovative development of exc As can be seen from the number of articles published by various countries in the field of embroidery (Figure 2), China started early in this field and is first in terms of an overall number of articles and citations, indicating a leading position in the world. China also ranks first in terms of a total number of articles and citations. With the advancement of technology and the promotion of silk culture throughout the course of the 'One Belt, One Road' project, Chinese embroidery-related researchers began to collaborate with foreign researchers, turning their horizons to the international arena. As a result, a series of studies on embroidery materials, techniques, and innovative designs emerged after 2016, leading to a significant increase in the number of articles published outside of China after 2016.
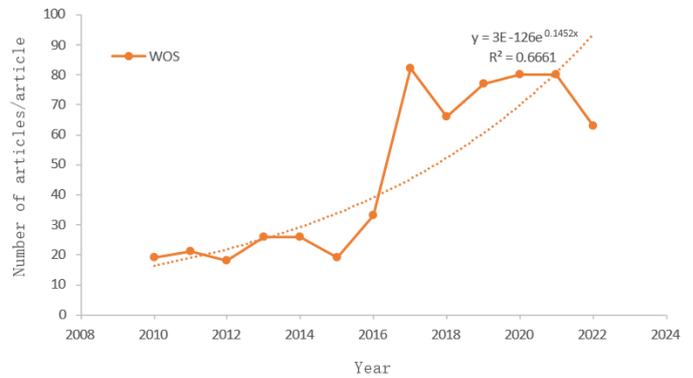

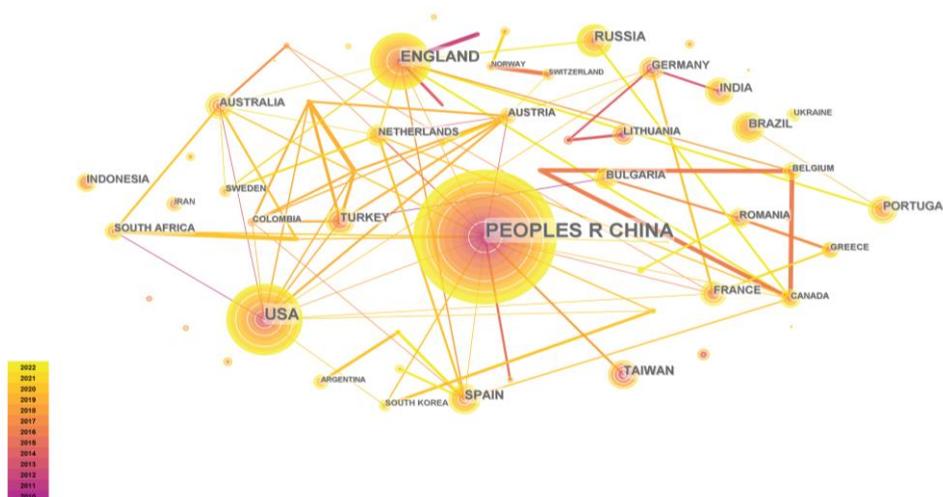Fig. 1. Changes in the number of publications.

Fig. 2. Country distribution of literature.

B. Analysis of the Study Authors

The top 10 scholars who published the most articles in China and abroad during 2010-2022 are shown in Table I, and the co-authorship network is shown in Figure 3. The author's co-authorship network in the English literature contains 326 nodes, 206 links, and a collaboration density of 0.0032, indicating that the intensity of collaboration between researchers is low.

Chung-Feng Jeffrey Kuo focuses on automated image colour analysis of different embroidered fabrics with a view to their practical use in the textile industry. He has formed a sizeable research team, of which Jian and Bo-Lin are part. Cristina Carvalho and Isabel Bieger are more profound collaboration partners, working mainly on bobbin lace to help preserve the craft. Zhengxing Sun belongs to Nanjing University and is the core of the team, leading members Yang, Kewei and, Wang, Shuang in the migration of embroidery styles and rendering of images through different algorithms to achieve better visual effects in the simulation of embroidery

TABLE I: TOP 10 AUTHORS OF ENGLISH LITERATURE

Author	Number of articles	Year Range
Chung-Feng Jeffrey Kuo	7	2011-2016
Zhengxing Sun	5	2018
Cristina Carvalho	4	2015-2020
Isabel Bieger	4	2015-2020
Juciene Milda	4	2010-2013
Perez-Bustos Tania	4	2017-2019
Wang Shuang	3	2018
Yang Kewei	3	2018
Jian Bo-Lin	3	2012
Haller Michael	2	2020

C. Analysis of Research Institutions

The ten institutions that had the most papers published between 2010 and 2022 are displayed in Table II. These institutions were categorised according to the different kinds and sizes of institutions, and duplicate articles were removed before compiling this list. Figure 4 presents the co-authorship network map broken down by institutional affiliation. There are 321 nodes in the English literature network, 124 connected lines, and a cooperation density of 0.0024. The level of cooperation between domestic and foreign publishers is low, which is analogous to the low level of co-authorship among writers. The number of publications at Jiangnan University is the greatest in China, followed by the number of publications at Nanjing University. The majority of China's publishing institutions are located in the more developed coastal sections of the country.

TABLE II: TOP 10 INSTITUTIONS

Institution	Number of articles	Year Range
Donghua University	9	2012-2022
Nanjing University	8	2014-2022
Russian Academy of Sciences	8	2012-2022
Kaunas University of Technology	7	2010-2014
Wuhan Textile University	6	2015-2017
National Taiwan University	6	2011-2016
Jiangnan University	6	2011-2022
Oradea University	5	2015-2017
University of Lisbon	4	2015,2019

The majority of the world's other research institutions for embroidery can be found at the Kaunas University of Technology, the Russian Academy of Sciences, the National University of Colombia, the University of Oradea in Romania, the University of Lisbon, and the University of the Philippines and the University of Lisbon, amongst other places.
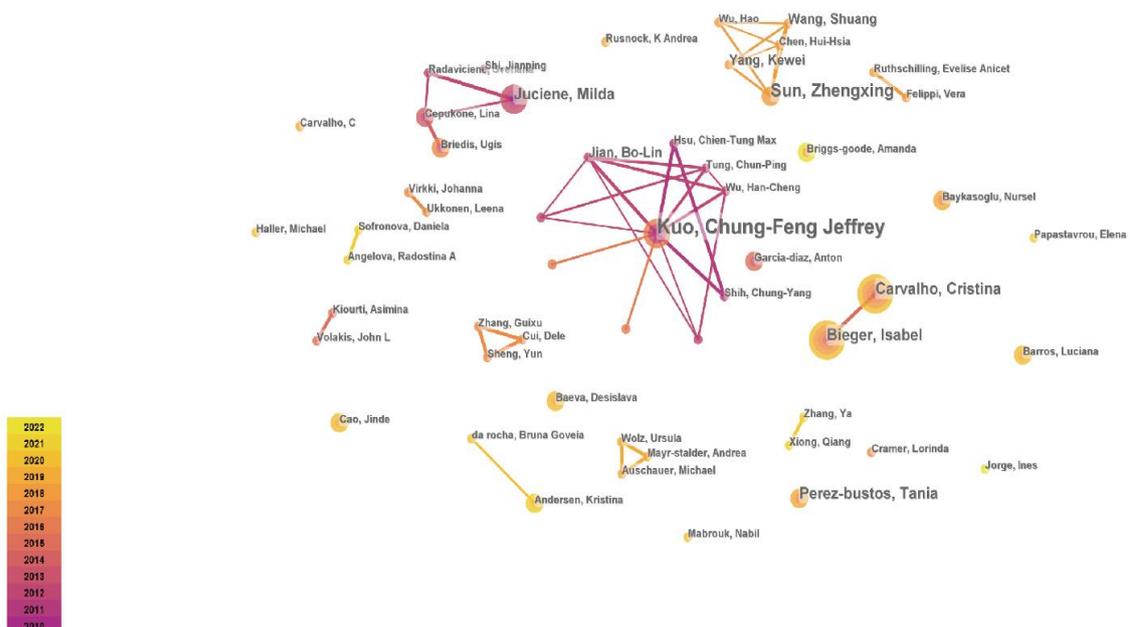
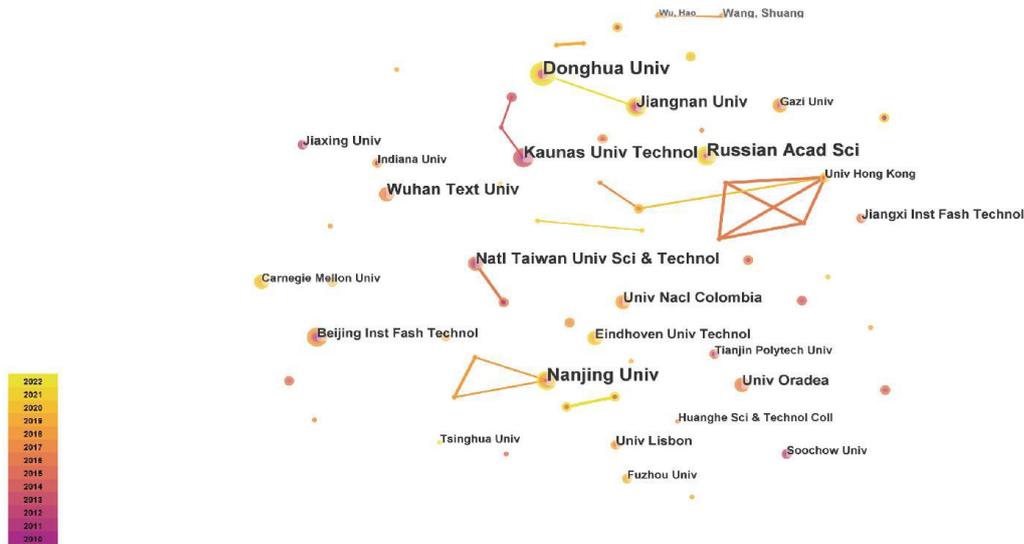Fig. 3. Co-authorship network of authors of articles

Fig. 4. Institutional co-authorship network.

Chinese institutions are responsible for 26.22 percent of all publications in the English language. Universities like as Jiangnan University, Donghua University, and Beijing Institute of Fashion Technology are examples of institutions that point to a leadership position and a key driving force in the industry. The majority of the publishing institutions have not yet established close collaboration with one another, according to the visual analysis performed by CiteSpace.

The exceptions to this rule are Donghua University and Jiangnan University, which have established quite deep cooperation. On the other side, despite the limited number of publications that have been published, Hongkong University is committed to fostering collaborative relationships with other educational institutions. An investigation of the institutions, on the other hand, finds that there is a relatively low level of coordination between them. In spite of the fact that a significant number of institutions are engaged in this kind of research, there has not been the development through time of a tight network of interaction between these institutions.

This is because needlework seems to be a regional art form, and many academic institutions prefer to finish their fieldwork by researching embroidery techniques in their local areas rather than travelling elsewhere.

D. Keyword Co-occurrence Analysis

This study analysed keywords in the embroidery field, and the "Keyword" option was selected to form a co-occurrence network map (Figure 5). Modularity is an indicator of the network's modularity, and a Q>0.3 means that the network association structure is significant. The Silhouette value is a measure of network homogeneity, and a Silhouette of 0.7 indicates that the clustering results are highly reliable[4]. The clustering profiles Q=0.9783, S=0.9708 in literature meets the essential requirements for network association structure and have high confidence in the clustering results.
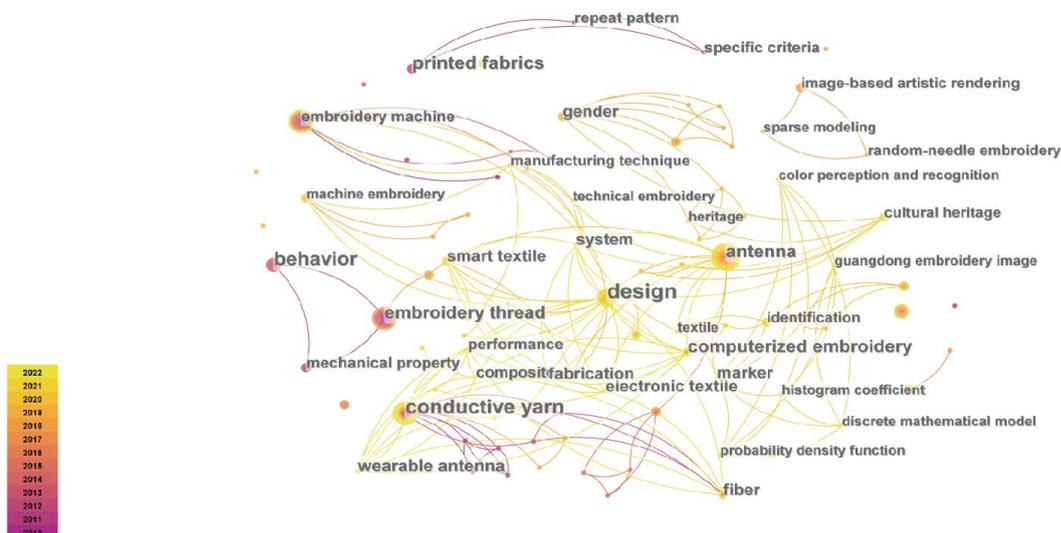
Fig. 5. Keyword co-occurrence mapping.

The top 10 hot keywords with high co-occurrence frequency in were selected (Table III). Five aspects of frequency of occurrence, degree centrality (the number of node connections), intermediary centrality (the number of times they act as the shortest link between two other keywords), and the year of initial and final occurrence powder (the year of first and final occurrence of a keyword between 2010 and 2022) were counted. A map of keyword co-occurrence networks corresponding to literature is formed, and we thus analyse the interconnection and evolution of hot keywords.

TABLE III: TOP 10 HIGH FREQUENCY OF HOT KEYWORDS AND THEIR RELATED ATTRIBUTES

Keywords	first occurrence	final appearance	Degree centrality	Frequency
Design	2020	2022	17	8
Conductive yarn	2012	2022	14	8
Embroidery machine	2010	2021	7	8
Embroidery thread	2010	2018	10	7
Antenna	2015	2022	10	7
Cultural heritage	2020	2022	6	5
Identification	2020	2021	6	5
Behavior	2012	2014	13	4
Printed fabrics	2011	2012	11	4
Computerized embroidery	2015	2022	10	4
Smart textile	2020	2022	8	4

By selecting the top 10 hot keywords with high co-occurrence frequency, it can be found that the hot keywords are divided into four clusters, which can be summarized into three areas of research: new embroidery fabric materials, computerized embroidery, and recognition and image computing of embroidery fabrics. In Table III, Unlike other countries, Chinese scholars have focused their research on design and cultural connotations. They are more adept at finding the human stories and artistic characteristics embedded in embroidery, as Chinese literature uses 'embroidery' more as a noun and focuses on traditional craftsmanship. In contrast, English literature uses more verbs and relates to machine embroidery. It is worth noting that scholars from Chinese institutions still focus on Chinese embroidery in their articles published both in China and abroad. However, the difference is mainly in their analytical approach. In their Chinese articles, qualitative analysis predominates. But in their English articles, more emphasis is placed on quantitative analysis, often using mathematical models and other simulations to propose solutions to embroidery problems.

1) Embroidery fabric materials

For more than a decade, along with the popularity of smart wearable products, clothing has been a necessity due to its contact with the human body, and researchers have begun to explore materials and production techniques for embroidered fabrics, making them an ideal platform for wearable electronics or sensors and a medium for understanding the human body while completing the embroidery pattern. A key driver of this research is the ability to quickly create large surface areas while manufacturing embroidered fabrics. The link between wearable technology and fabrics was further discussed at The Smart Fabrics Conference 2014, which was renamed Smart Fabrics and Wearable Technology. Smart textiles, e-textiles and interactive textiles have also been clearly defined. Smart textiles, e-textiles and interactive textiles have also been clearly defined [5].

Alagirusamy *et al*. [6] address the problem of short-circuiting due to friction, washing, material contact, etc., through the use of polypropylene in the integration of conductive yarns with electronic devices and sensors on fabrics through weaving and embroidery processes. Poniecka *et al*. [7] introduced the possibility of using natural fibre composites in machine embroidery. Radaviciene [8] investigated the effect of different linear densities of embroidery threads on the accuracy of embroidery patterns in machine embroidery.

2) Machine embroidery

Due to the slow speed and low reproducibility of hand embroidery, developed countries have focused more on machine embroidery than China, not only manufacturing higher levels of embroidery machines overall but also developing software earlier than China and taking a large market share ahead of China, such as wilcom in Australia and Tajima and Barudan in Japan. Analysis of the citespace software reveals that the English language literature in this field focuses on the improvement of embroidery machine parts and techniques and that the overall research predates that of China, suggesting that Chinese research in machine embroidery draws on foreign sources but that many types and different stitches of Chinese embroidery have given rise to comparative studies of hand and machine embroidery stitches.

Loita *et al*. [9] conducted observations and interviews with machine embroiderers in five different locations to promote machine embroidery in Indonesia [9]; Zhang *et al.* [10] proposed a humanoid cross-stitch machine design to address the problem of reduced quality of machine embroidery on embroidered fabrics without cross grids [10]; Vital *et al*. [11] used an embroidery machine where the embroidery pattern significantly affected the wear performance when using conductive textile microstrip threads on denim fabrics[11].

3) Identification and image analysis of embroidered fabrics

Embroidery materials reflect the changes in the progress of human society, both in time and space. The materials, techniques, patterns, and colours are often closely related to the needs or background of human society at a certain stage, reflecting the cultural connotations of the country or nation. A large number of scholars, both in China and abroad, continue to identify and analyse textile artifacts in order to uncover more historical information or to use new

technologies to help such cultures to be better preserved and presented.

Zhang *et al.* [12] in Perception and identification of colours in Canton embroidery weaving through discrete mathematical models to help build a colour database for Canton embroidery. Vryzidis *et al.* [13] discussed different types of textiles used for sanctuary door curtains in Orthodox churches during the Ottoman period, illustrating the connection between Byzantine traditions and the Ottoman cultural environment in terms of images and their symbolic meaning; Chung-Feng Jeffrey Kuo *et al.* [14] Pattern-making simulation on embroidery using probabilistic neural network and texture fitting method", based on a probabilistic neural network, texture fitting method to visually simulate the real effect of embroidery.

IV. ANALYSIS OF CUTTING-EDGE RESEARCH THEMES BASED ON KEYWORDS WITH THE STRONGEST CITATION BURSTS

For comprehensive judgment and detection, research frontiers must be analyzed based on synonyms, combined with an analysis of the literature in which the synonyms are found. Using CiteSpace burst detection analysis, the minimum duration threshold was set to 2 years. Visual analysis was conducted to obtain the distribution of burst words for research in the field of embroidery (Fig. 6), which can be used to understand the cutting-edge issues in the embroidery field at different times. In English, there is only one prominent keyword, "design."

Top 1 Keywords with the Strongest Citation Bursts

Keywords	Year	Strength	Begin	End	2010 - 2022
design	2010	2.84	2020	2022	

Fig. 6. Keywords with the strongest citation bursts.

It can be found that the international embroidery research field does not show multiple keywords proliferation of phenomenal response themes.As it is too vague to generalize the frontier themes only through the word "design," the analysis and classification of the literature included in "design" show that the main frontier themes are:

1) The design of embroidery technology

Embroidery technology, which mainly refers to the design of process parameters, hardware and programs for machine embroidery for better use on industrial or smart fabrics. Ursula Wolz et al. present the basic principles and innovative core of TurtleStitch, a pattern design software for machine embroidery that can be used to navigate sewing needles through the fabric using an algorithm to complete the design, to some extent breaking through the embroiderer's The software allows the design to be navigated through the fabric by an algorithm that breaks through the limitations of the embroiderer's tools [15]. Based on the handling problems of metal clamps used to clamp fabric in computerized embroidery machines, Yang *et al.* [16] proposed the structural design of the SMP clamp, which is presented to demonstrate the potential of the SMP clamp to replace metal clamps.

2) The design of smart textiles

Smart textiles are textiles with the ability to react to different physical stimuli; mechanical, electrical, thermal and chemical, etc. Through the design of materials, patterns, and production processes for smart fabrics, more possibilities are explored for the practical use of smart fabrics. Swielam *et al.* [17] compared the changes in the conductivity of embroidery threads under different process parameters for machine embroidery in order to find the best results. Rho *et al.* [18] proposed an equivalent circuit model and calculation formula for the consumption of conductive yarns through embroidery design parameters and analyses the influence of embroidery design parameters on the appearance and electrical characteristics of conductive yarns.

V. CONCLUSION

The collected data indicates a general increase in the number of articles on embroidery, indicating that interest in the area continues to expand and that machine embroidery is receiving a growing amount of attention. Researchers at the majority of academic institutions and universities are the driving force behind embroidery research. As the majority of craftsmen are unable to conduct their own study, they must join university research teams to complete a series of studies. This study provides two trends and recommendations based on the findings of the analysis.

1) Aesthetical characteristics of machine embroidery

Embroidery fabric materials, machine embroidery, recognition, and image analysis of embroidered fabrics are the hot spots of research, and embroidery technology and smart textiles are the Frontier research themes. Researchers are keen to develop embroidery technology and smart textiles about design, following the technological trend and serving as a reference for Chinese researchers in this area.

However, an analysis of the posting institutions reveals little collaboration between institutions. So far, although there are a huge number of institutions engaged in this type of research, a close network of collaboration between institutions has not developed over the years, which is related to the apparent regional nature of embroidery, with many institutions preferring to study the embroidery processes of the region in order to complete fieldwork. In contrast to China, which adopts a multidisciplinary approach and focuses on the humanistic aspects of embroidery, international researchers primarily follow historical and archaeological approaches and do not pay special attention to the artistic qualities of embroidery, which are frequently archaeological in terms of dyes, techniques, etc., and which [19–22], although interpreted appropriately in relation to the social context, lack a systematic analysis of ancient weaving and embroidery motifs from an art historical perspective. The creative investigation of old weaving and embroidery patterns is limited. While pursuing international hotspots, international researchers should focus on the "humanistic" aspect of hand embroidery, whether the patterns left by the ancients have deeper connotations and unique aesthetics, whether traditional patterns can be innovatively applied to machine embroidery, and on adding cultural connotations

while enriching the pattern library of machine embroidery, rather than blindly pursuing modern design, fashion, and mass production.

2) Machine embroidery that simulates hand embroidery

State policy has significantly influenced the development of Chinese embroidery study. Chinese society and culture are characterised by a top-down sociocultural framework, and government policy control and support are the most important variables in its growth. Although information technology has been very beneficial to embroidery research, the practical application of emerging technologies, guided by intangible cultural heritage policies, has become a hot topic of academic debate as to whether it can effectively help craftspeople do their work, whether it can serve as a legacy while preserving resources, and the relationship between machine and human embroidery, giving rise to different research priorities for machine embroideries. The presentation of machine embroidery in China must frequently be compared and simulated with traditional hand embroidery, in the hope that machine embroidery can imitate hand embroidery and inherit traditional stitches and effects via machines, despite the fact that this is also necessary to address the problems of insufficient manpower and expensive hand embroidery. It is easy to overlook the legacy of traditional artistry in worldwide research on machine embroidery, which focuses primarily on the aesthetics and functionality of needlework for industrialization. The enhancement of machine embroidery necessitates the extraction of hand embroidered stitches and techniques in order to optimise them. In this procedure, worldwide machine embroidery research could concentrate more on the similarities and contrasts of traditional stitches across nations in order to demonstrate additional machine embroidered effects.

In the future, the current research hotspots will continue with little change. However, more and more Chinese scholars in the field of embroidery will gradually move closer to foreign scholars and focus on the study of smart fabrics and embroidery technology so that machine embroidery can be better applied and benefit from the preservation and inheritance of embroidery culture. The interdisciplinary research trend will continue to deepen, and the publications suggest that the study and application of digital technology have become an inevitable issue in the development of embroidery research.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Conceptualization, Jiajun Chen and Ya Zhang; methodology, Jiajun Che and Ya Zhang; formal analysis, Jiajun Chen; investigation, Jiajun Chen and Ya Zhang; data curation, Jiajun Chen; writing—original draft preparation, Jiajun Chen; writing—review and editing, Jiajun Chen; supervision, Ya Zhang; All authors have read and agreed to the published version of the manuscript.

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