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A study of Citespace-based deep learning applied to face recognition

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Abstract. Face recognition technology has made significant progress in recent years, driven by deep learning and other technologies, and is widely used in public safety, financial payment, intelligent access control, and other fields. Deep learning can effectively extract discriminative features from face images by constructing neural network structures and automatically learning feature mapping relationships, to improve the recognition accuracy. Deep learning shows excellent robustness when dealing with complex scenarios, and scientific metrology and visual analysis tools such as Citespace play an important role in analyzing the current status and development trend of applied research in the field of face recognition. Deep learning methods such as data enhancement techniques and generative adversarial networks have shown strong performance in face recognition tasks. In the future, the further integration and development of deep learning and face recognition technology will promote technological innovation and application expansion. Face recognition technology has important application potential in the digital society and will have wider application prospects in the future.

Keywords: Face Recognition, Deep Learning, Citespace, Visual Analytics

1. Introduction

With the rapid development of information technology, face recognition technology, as a kind of biometrics, has been widely used in many fields such as public security, financial payment, intelligent access control, and so on due to its convenience, non-contact, and high security. However, traditional face recognition methods often show certain limitations in the face of complex and changing real-world scenarios due to factors such as lighting changes, expression gestures, and occlusions. In recent years, the rise of deep learning technology has injected new vitality into the field of face recognition, and its powerful feature learning and classification capabilities have greatly promoted the development of face recognition technology.

By constructing a neural network structure with multi-layer nonlinear transformations, deep learning can automatically learn the mapping relationship from the original input to the high-level abstract features, to effectively extract the discriminative features in the face image. These features are not only crucial for the face recognition task, but also show excellent robustness when dealing with various complex scenes. Therefore, the application of deep learning in face recognition has gradually become a hot research topic.

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In order to systematically understand the current status and development trend of the application of deep learning in the field of face recognition, this paper adopts Citespace, a scientifically metrological and visual analysis tool, to conduct an in-depth exploratory study of the relevant literature. Through the visual display and analysis of keyword co-occurrence, author cooperation, and other information of a large number of literatures, we expect to reveal the main research hotspots, key technologies and development trends of deep learning in the field of face recognition, and provide valuable references and insights for researchers in related fields. At the same time, we also hope that the research in this paper can promote the further integration and development of deep learning and face recognition technology, and promote technological innovation and application expansion in related fields.

2. Literature review

2.1. Literature findings

Face recognition technology has made remarkable progress in recent years.Face recognition technology has improved recognition accuracy and solved the challenges of light and posture variability through technological innovations such as deep learning, sparse models and fuzzy set theory. Ali, W et al.[1] summarised many important roles of this technology in many practical applications, such as surveillance, security, and unlocking of mobile phones, which bring more convenience to people's lives. Meanwhile, face recognition has important application potential in digital society and will have wider application prospects in the future.

Singh, N et al.[4] believe that machine learning and deep learning play a key role in face recognition technology. Data enhancement techniques are widely adopted and face datasets are costly to construct and annotate. Deep learning methods have shown strong performance in face recognition tasks such as Generative Adversarial Networks for 3D face generation studied in depth by Toshpulatov, M et al.[3] These techniques continue to drive technological innovation and progress in the field of face recognition.

Adjabi I et al.[2] believe that different face recognition techniques (e.g., 2D, 3D methods) and their challenges (e.g., pose changes, lighting changes, facial expressions, etc.) have also been a key direction of focus in the study of face recognition techniques. Morales, A et al.[5] found that as the technology continues to evolve, deep learning strategies are becoming the standard choice to replace the widespread statistical model fitting. Meanwhile, Ahmed, SB et al.'s[6] in-depth discussion on the complexity of face recognition and the way to categorise facial expressions in 3D representations also provides us with new perspectives and research directions. These studies will help to further promote the development and application of face recognition technology.

Evaluating the diversity and size of metrics and datasets is still one of the current challenges. Alexandre, GR et al.[7] considered 3D facial expression recognition as a rapidly developing field, focusing on face representation, preprocessing and classification experiments. However, the study found shortcomings in the reporting of preprocessing techniques and challenges in fair comparison between multiple methods. This informs important decisions for researchers, and Alzu'bi, A et al.[8] are further exploring technical issues such as how to improve network structure, feature extraction, datasets and evaluation metrics.

Ming, ZH et al.[9] identified prevention of facial deception (PAD) and presentation attack detection as one of the popular future research directions. Several methods have been developed to tackle this challenge, with deep learning based methods showing promising results. However, a study by Abdullakutty, F et al.[10] demonstrated significant performance degradation of existing methods on different datasets, and there is still the critical problem of detecting invisible attacks. Therefore, future research needs to improve the generalisability of machine learning methods and create more stable techniques for demo attack detection for a wider range of unknown samples.

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2.2. Citespace Applications and Benefits

In this paper, we will use the Citespace tool to visualise and analyse the literature on deep learning in face recognition. By displaying and analysing the keyword co-occurrence, author collaboration and other information of a large number of literatures, we will reveal the research hotspots, development trends, as well as the core authors and institutions in the field. The visualization function of Citespace can present the complex analysis results in the form of intuitive and easy-to-understand graphs, which enables the researchers to quickly grasp the overall structure of the field and the key nodes. This will help us to have a more comprehensive understanding of the current status and future development direction of the application of deep learning in face recognition.

3. Research Methods and Data Sources

3.1. Research method

This study adopts a comprehensive scientometric and visual analytical approach, aiming to deeply explore the current research status, development trend, and collaborative network of deep learning in the field of face recognition. The specific research methodology includes the following aspects:

- Literature search and screening: subject-related literature search was conducted in the core database of Web of Science (WOS), and research papers related to deep learning in face recognition within the last five years (2019-2023) were collected by setting specific search terms and screening conditions to ensure the timeliness and relevance of the data.
- Co-word analysis and clustering: co-word analysis of keywords in the literature, identification of high-frequency keywords and thematic clustering, which in turn reveals the main research directions and application scenarios of deep learning in the field of face recognition.
- Author and country collaboration analysis: by extracting author information and country data in the literature, we analyse the core authors, research institutions and international collaborations in the field, demonstrate the collaboration network, and reveal the characteristics and trends of academic collaborations.
- Visual Graph Interpretation: Interpret and discuss the analysis results by combining the visual graph generated by Citespace. Through the node size, link strength, colour and other information in the graph, the current status and development trend of the application of deep learning in the field of face recognition will be demonstrated visually.

3.2. Data sources

The data source of this study is the authoritative academic database Web of Science, which contains high-quality academic journals and conference papers from all over the world, with wide coverage and high authority. By defining the database as "Web of Science Core Collection" and the language as "English" in WOS, the academic and linguistic consistency of the data is ensured. In this study, the search period was set from 2019 to 2023. This time span can cover the important research results and developments in this field in the past 5 years. After rigorous screening and quick filtering, we finally retrieved a total of 1,452 valid literatures. These literatures constitute the data base and the object of analysis of this study. During the retrieval process, we paid special attention to keywords and topics related to deep learning in face recognition to ensure the relevance and accuracy of the data. We also recorded the retrieval time node as 28 December 2023 for subsequent data updates and comparative analysis.

Based on these high-quality data sources and rigorous research methodology, this study is able to more objectively and comprehensively reveal the current research status and development trend of deep learning in the field of face recognition as well as the research contribution of the core team. At the same time, it also provides a solid data support and theoretical foundation for the subsequent analyses and discussions.

4. Analysis of the current state of research on the application of deep learning in face recognition

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4.1. Critical co-occurrence

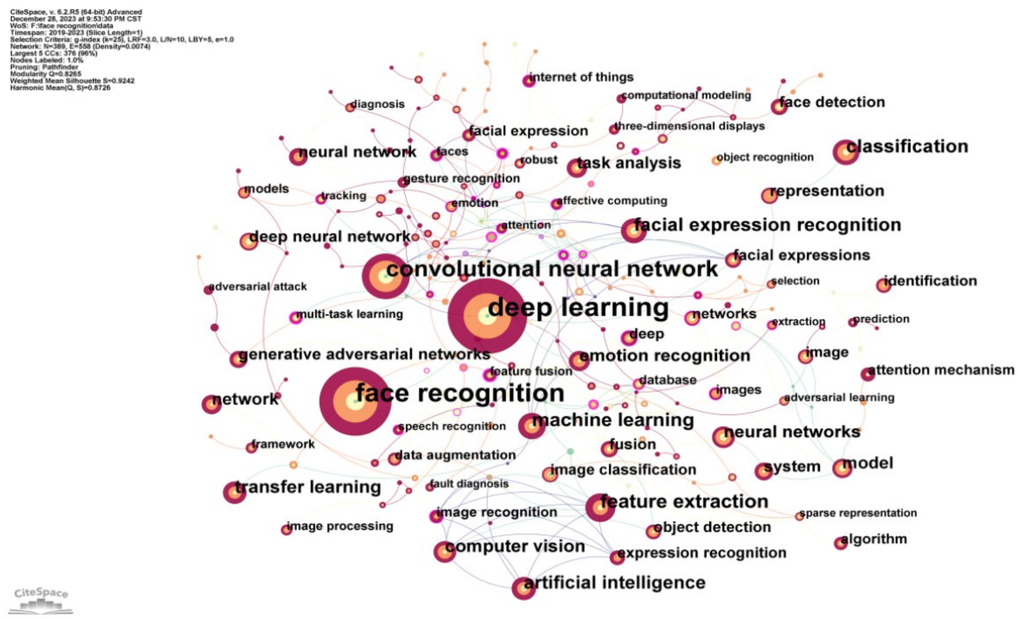

Figure 1. Critical co-occurrence.

The keywords in the literature can accurately reflect the core content of the article, and the analysis of the centrality of keyword intermediaries in the existing research can show the hot issues in the field. Using Citespace software to analyse "Keyword", the results are shown in Figure 1. The keywords with high centrality are age (0.29), pattern recognition (0.28), patterns (0.25), emotions (0.24), systems (0.23), feature fusion (0.22), multi-task learning (0.2), and head pose estimation (0.2). These terms have a high frequency of occurrence in the last five years of research, and they co-occur with other keywords more frequently. In terms of research hotspots and trends, the high centrality of AGE and EMOTIONS may reflect the gradual increase in the importance of affective computing and age-related factors in AI systems; PATTERN RECOGNITION and PATTERNS reflect the central position of pattern recognition in deep learning. For technology applications and concerns, keywords such as feature fusion, multi-task learning and head pose estimation indicate the diversity of technology applications and specific concerns. Feature fusion is crucial for improving the performance of deep learning models, multi-task learning helps models make progress on multiple related tasks simultaneously, and head pose estimation has a wide range of applications in human-computer interaction, virtual reality, and other fields. Systems as a high centrality keyword reflects the increasing emphasis on overall system design and integration in deep learning research. These keywords also show the cross-fertilisation of deep learning with other fields, such as cognitive science (age, emotions), computer vision (pattern recognition, head pose estimation), etc., suggesting that deep learning is widely penetrating into various subject areas as an enabling technology.

4.2. Keyword clustering

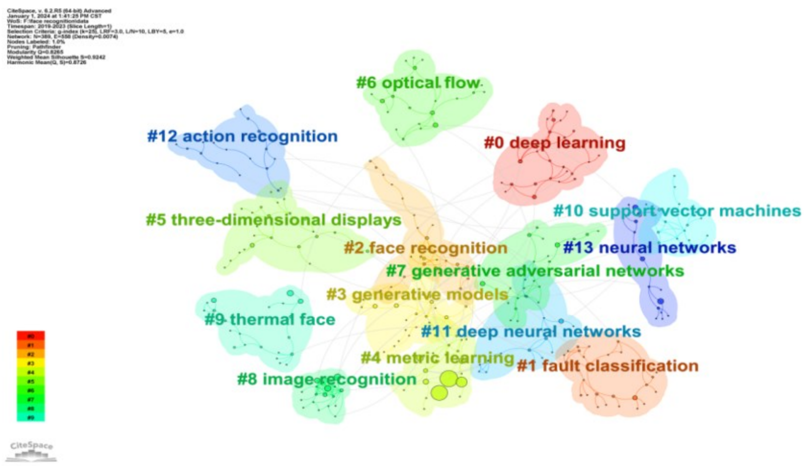

Figure 2. Keyword clustering.

From Figure 2, it can be seen that the clustering analysis of the keywords leads to the classification of AI deep learning fields into deep learning, fault classification, face recognition, generative models, metric learning, three-dimensional dispalys, optical flow, generative adversarial networks, image recognition, thermal face, support vector machines, deep neural networks, action recognition, neural learning, and deep learning. recognition, neural networks, and other 14 major research directions. The clustering of the top four keyword contour values is shown in Figure 3.

Clustering	Cluster name	Contour value	Keyword subclustering
#9	transfer learning	1	gesture separation network、gait recognition、face recognition、gait recognition、benchmark testing、legged locomotion、gait dataset
#8	image recognition	0.982	face de-identification、data privacy、feature extraction、artificial intelligenc、neural networks、visual speech recognition、learning loss function
#7	generative adversarial networks	0.965	image reconstruction、neural networks、task analysis、feature extraction、face photo-sketch synthesis、logic gates、residual neural networks
#10	support vector machines	0.942	training data、image recognition、intensity estimation、task analysis、deep learning、feature extraction、generative adversarial networks、logic gates

Figure 3. Keyword clustering table.

As can be seen from Figure 3, several important research directions in the field of deep learning for face recognition are transfer learning, image recognition, generative adversarial networks, support vector machines, deep neural NETWORKS, where the keyword group represented by transfer learning mainly includes GESTURE SEPARATION NETWORK, GATHER RECOGNITION, FACE RECOGNITION, indicating the important role of transfer learning in several specific application scenarios. Transfer learning allows a model to apply the knowledge learnt from one task to another related task, and in terms of social phenomena, these clusters also reflect the wide application and far-reaching impact of AI technology in social life. For example, face recognition technology has been

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widely used in a variety of fields such as public safety, identity verification, social media, etc.; while gait recognition plays an important role in medical diagnosis, elderly guardianship, and security monitoring. The growing demand for these applications is also driving research and development in related technology areas. Research institutes and enterprises may pay more attention to the direction of technology that can improve model generalisation ability and reduce data dependency, such as migration learning, thus forming a certain research aggregation in the fields of face recognition and gait recognition.

The keyword cluster represented by image recognition mainly includes face de-identification, data privacy, and feature extraction. From the policy level, with the increasingly strict regulations on personal privacy and data protection worldwide, such as the EU's GDPR, image recognition technology must pay more attention to privacy protection in the application process. Face de-identification technology has thus emerged, which is capable of removing or modifying personally identifiable features while preserving image information, so as to analyse and exploit images without violating data privacy regulations. Therefore, face de-identification, data privacy, and feature extraction have become keywords closely related to image recognition.

The keyword cluster represented by generative adversarial networks mainly includes image reconstruction, neural networks, and task analysis.This clustering presents a close logical relationship at the technical and application levels.GANs as a neural network-based GANs, as a neural network-based generative model, has the core mechanism of generating realistic data samples through adversarial training, and has excellent performance especially in the image domain. Image reconstruction, as one of the important application scenarios of GANs, plays an important role in medical image processing, old photo restoration, and super-resolution reconstruction by taking advantage of the fact that GANs can generate high-quality images. Meanwhile, neural networks, as the cornerstone of GANs, provide powerful representation and generation capabilities for GANs with their deep structure and learning capabilities. Task analysis, on the other hand, is the key link to evaluate and optimise the performance of GANs. Through in-depth analysis of the quality and diversity of generated samples as well as the stability of model training, it helps to promote the continuous improvement and expansion of GANs in practical applications.

The keyword clusters represented by support vector machines mainly include training data, image recognition, intensity estimation, etc. From a technical point of view, the logical relationship between the formation of such clusters lies in the following: SVMs, as a powerful classification algorithm, need to rely on high-quality training data when dealing with problems such as image recognition. As a powerful classification algorithm, SVMs need to rely on high-quality training data to extract effective features when dealing with problems such as image recognition; at the same time, in some application scenarios, preprocessing techniques such as intensity estimation can further enhance the performance and accuracy of SVMs. These keywords are interrelated and mutually reinforcing, and together they form a complete picture of SVMs applications in machine learning and related fields.

4.3. Keyword time zone

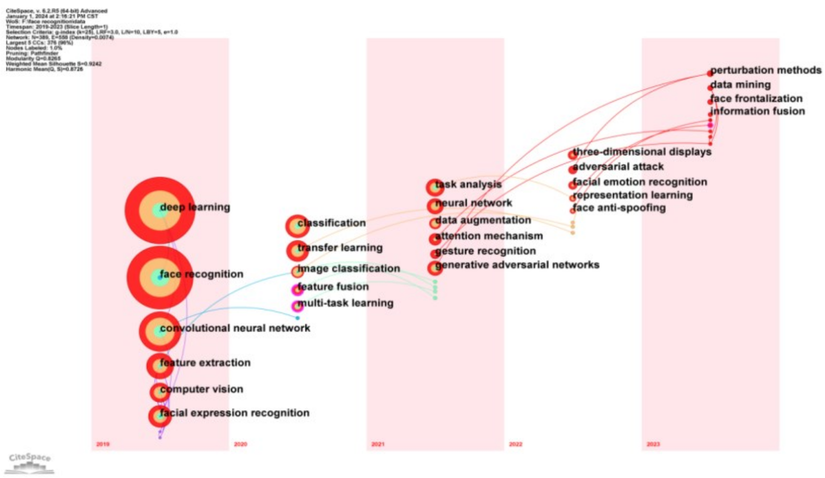

Figure 4. Keyword time zone.

As can be seen from Figure 4, the research in the field of deep learning of face recognition is mainly divided into five stages. In 2019, the main researches are Deep Learning, Face Recognition, Convective Neural Network, feature extraction, computer vision and facial expression recognition. At this time, the government paid more attention to the field of artificial intelligence and began to introduce a series of support policies, such as providing research and development funds and building data centers, which created conditions for the development of deep learning technology.

The main research in 2020 includes classification, transfer learning and image classification. With the further development of technology, academic circles began to pay attention to more advanced application research such as classification and transfer learning, and at the same time promoted the optimization and improvement of the algorithm to improve the accuracy and generalization ability of the algorithm.

In 2021, the main research includes task analysis, neural network, data augmentation, attention mechanism, etc. At this time, the market demand for more complex tasks increases, such as autonomous driving and intelligent customer service. The research turns to deeper theoretical and methodological innovations, such as neural network improvement, data enhancement and attention mechanism, etc. At the same time, academic circles pay more and more attention to the ethics and safety of technology.

In 2022, the research focused on the frontier fields such as three-dimensional displays and adversarial attack. These research directions reflect the expansion and application of deep learning technology in virtual reality, augmented reality and network security. At this time, government policies began to pay attention to the innovation ecology and industrial chain construction of artificial intelligence technology, and promoted the formation of a more perfect and collaborative innovation system.

In 2023, the research focused on perturbation methods, data mining, face frontalization, information fusion and so on. These research directions show that the field of deep learning has begun to pay more attention to cross-disciplinary and interdisciplinary integration to solve more complex and challenging tasks. At this time, while continuing to support technological innovation and application, government policies have also begun to pay attention to the social impact and governance of artificial intelligence technology, and promote the healthy development of technology and the realization of social value

5. Analysis of core authors and institutions

5.1. Author Collaboration

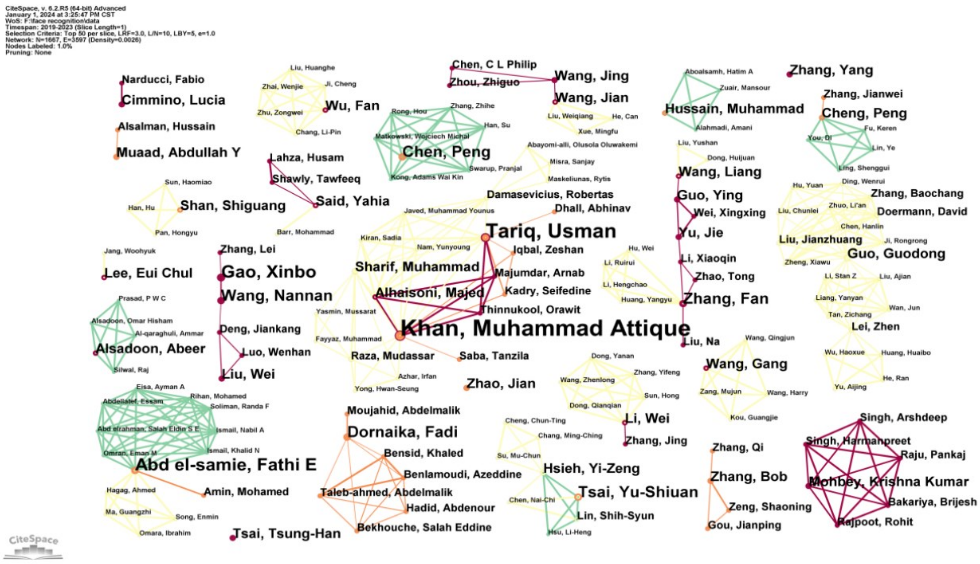

Figure 5. Author Collaboration Chart.

The author cooperation network obtained through visual analysis is shown in Figure 5. It can be seen from the figure that there are 1667 nodes and 3597 connections in the author's cooperative network, and the correlation density is 0.0026. The low density indicates that the cooperation between scholars is not close enough. Among them, there are several cohesive scientific research teams: Team 1 is composed of scholars such as Khan, Muhammad Attique, Tariq, Usman, Alhaisoni, Majed, Iqbal, Zeshan, etc. The team has a complex network of relationships, and many scholars have cooperated, among which the core scholar is Khan, Muhammad Attique, who has published 10 papers. This scholar has been paying attention to biological signals since 2021. Team 2, represented by Abd El-Samie and Fathie, has a high number of papers and close cooperation. Among them, Abd El-Samie and Fathie occupy the first place with five papers, while other authors have one paper. The research focus of this team is more on image super-resolution technology; Team 3 Mohbey, Krishna Kumar, Singh, Singh, Arshdeep, Singh, Harmanpreet, Raju, Pankaj, Bakariya, Brijesh, Rajpoot, Rohit have close cooperation, and these four scholars began to pay attention to this field in 2023. In addition, independent scholars such as Tsai, Yu-Shiuan, Zhao and Jian have also made great contributions to the research in this field.

From the perspective of cooperation network, although the current cooperation density is low, with the increasing complexity of scientific problems and the rise of interdisciplinary research, researchers in the field of deep learning face recognition may be more inclined to form close cooperation relationships in the future. This kind of cooperation is not only limited to scholars, but may also be extended to institutions, laboratories, and even countries, in order to jointly overcome technical difficulties and promote the rapid development of the field.

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5.2. Institutional Cooperation

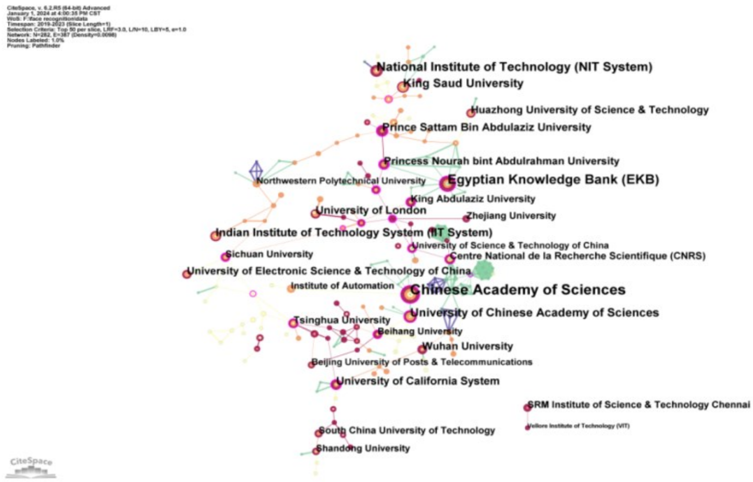

Figure 6. Institutional Cooperation Chart.

From Figure 6, it can be seen that there are 282 nodes and 387 connecting lines in the cooperation network of issuing institutions for face recognition deep learning research, with a density of 0.0098, which indicates that the overall density of cooperation between the issuing institutions is small, and the issuing institutions are looser. The main research groups with strong co-operation are: group 1 is led by the Chinese Academy of Sciences, which leads other research institutions to form a close network of research institutions, and has been involved in this field since 2020, and continues to this day; group 2 includes the Egyptian Knowledge Bank (EKB), Prince Sattam Bin Abdulaziz University, King Abdulaziz University, etc. This group has Egyptian Knowledge Bank (EKB) as the core institution with 37 literature results. Group 3 includes National Institute of Technology (NIT System), King Saud University, etc., which has National Institute of Technology (NIT System) as its core institution and has 30 literature outputs. In addition, the analysis also reveals that there is a correlation between a low degree of contact with the issuing institution and a weak cooperation relationship between the issuing authors.

In the field of deep learning, the current situation of academic cooperation and team building is characterized by both fragmentation and concentration. On the one hand, on the whole, the density of both author collaboration networks and institutional collaboration networks is low, indicating that the collaboration between scholars and institutions is not yet close enough. This may be due to the specialised and competitive nature of the field, which makes interdisciplinary and inter-institutional collaboration relatively difficult. However, on the other hand, we can also observe some obvious core authors and institutions that have formed influential research teams and achieved significant research results in specific directions through close internal collaboration. These teams usually consist of several core scholars whose research directions complement each other, and who work very closely with each other to advance their research. In addition, although the teams are generally small in size, their core members are stable and their research directions are clear, which enables them to explore deeply in their respective fields and develop research characteristics. However, team building is a long-term process that requires continuous investment and efforts, especially in the rapidly evolving field of deep learning, where teams need to constantly update their research directions, introduce new talents and expand their collaboration networks in order to maintain competitiveness and innovation. Therefore, in order to promote the further development of the field of deep learning, we need to strengthen the cooperation and exchange between scholars and institutions, break down disciplinary and institutional barriers, and promote interdisciplinary and inter-institutional cooperation and innovation.

6. Conclusion

We can predict that the development of deep learning face recognition technology will present the trend of diversified integration and continuous innovation. The fusion of emotional computing and age factors will give face recognition richer intelligent connotations, making it better adapted to the needs of different user groups. At the same time, the deepening of pattern recognition, multi-task learning and feature fusion will jointly improve the accuracy and generalisation ability of the model, providing strong support for the application of face recognition technology in complex scenarios. In addition, the extended application of head pose estimation will further broaden the application areas of the technology to meet the development needs of virtual reality, augmented reality and other cutting-edge fields. In terms of system design and integration, optimising the overall architecture and enhancing modularity and scalability will become an important trend to adapt to changing application scenarios. As global awareness of privacy protection increases, privacy protection and ethical issues will also become a core concern in the development of this field, promoting the widespread application of face recognition technology under the premise of compliance with regulations and ethics. Government support and policy guidance will continue to promote technological innovation and industry chain improvement, accelerate the commercialisation of deep learning face recognition technology, and maximise its social value in public safety, identity verification, social media and other fields. At the same time, cross-field and interdisciplinary cross-fertilisation will inject new vitality into the field and promote the overall progress and development of AI technology.

In summary, based on the results of Citespace's analysis and current research dynamics, we predict that deep learning face recognition technology will develop in the future towards closer cooperation, stronger core influence, and more focus on practical applications and team building. These trends will not only provide new opportunities and challenges for researchers in this field, but also promote deep learning face recognition technology to achieve application and value in a wider range of fields.

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