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Facial Recognition Technology: Methods and Challenges

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Abstract. With the development and progress of science and technology, facial recognition has become an important research direction in the field of computer science and has been widely applied in areas such as identity verification and security. This paper systematically reviews traditional and emerging face recognition methods, covering classic algorithms such as two-dimensional principal component analysis (2DPCA), as well as the rapidly developing deep learning techniques in recent years. Among them, the face recognition method based on deep convolutional neural networks has significantly improved the recognition accuracy and robustness compared with the original two-dimensional principal component analysis algorithm. For complex scenarios such as occlusion, illumination changes and posture differences,this paper introduces an improved method based on attention mechanism, generative adversarial network, and 3D point features. These approaches significantly enhance recognition accuracy in challenging scenarios, particularly in occluded settings such as wearing masks, and under special conditions including weak lighting.In addition, this paper summarizes the bottlenecks in the current research status and points out the future development directions and trends.

Keywords: Facial Recognition, Two-Dimensional Principal Component Analysis (2DPCA), Deep Learning, Convolutional Neural Networks (CNN), Occlusion and Illumination Variation

1. Introduction

With advancements in artificial intelligence and computer science, facial recognition has increasingly emerged as a pivotal branch within the field of computer vision. It finds extensive application in security surveillance, identity authentication, and mobile payment. It offers a user-friendly and intuitive interface, with broad applicability across various fields. As a result, this area has become a focal point of current research in computer science [1-3].

Facial recognition refers to a technology that analyzes, models, and compares computer-inputted images to ultimately confirm individual identity [4, 5]. This research aims to achieve accurate facial identification under varying environmental conditions.

This thesis provides a comprehensive overview of facial recognition methods under conventional conditions, as well as those designed for special circumstances. Present limitations are discussed, followed by an analysis of future development trends. This thesis attempts to trace the evolution of facial recognition technologies, summarize key research achievements, and critically analyze current

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technical limitations. The future direction of the field is explored. Practical references are provided for subsequent investigations.

2. Conventional facial recognition methods

Distinguishing features from large-scale data samples. As a result, these methods more effectively discriminate among individual identities. Deep convolutional neural networks incrementally capture image edges, textures, and assorted visual information across successive layers. High-level abstractions are constructed for identity classification and feature matching. Compared to legacy techniques, deep learning exhibits superior robustness. Recognition rates show marked improvement when applied to extensive facial image repositories.

Taken together, deep learning not only advances the intelligence and accuracy of facial recognition technologies but also constitutes a pivotal force shaping the future of this field.

3. Facial recognition under special conditions

3.1. Facial recognition in occluded settings

real-world facial recognition scenarios routinely present challenges such as facial occlusion. Traditional recognition methods lose efficacy in such contexts. During public health events, for example, widespread mask usage resulted in occlusion of the nose and mouth. These occluded regions eliminate key distinguishing features. Precision in standard facial recognition systems was severely compromised. Recognizing these limitations, further technical optimization became necessary. Typically, researchers address occlusion through two complementary strategies: The first centers on the blocked region. Relevant approaches include using deep learning frameworks or generative adversarial networks to reconstruct, predict, or generate complete facial imagery. The second strategy focuses on the visible, unoccluded segments of the face. Improving original recognition techniques allows more thorough utilization of available information. Maximizing valid data is thereby achieved. By integrating local recognition and occlusion prediction, high-precision facial recognition in occluded conditions becomes feasible, greatly enhancing system robustness.

For instance, Su Xueping and colleagues proposed an algorithm for mask-occluded facial recognition [5], which integrates multi-view features. Initial algorithm design prioritizes overall accuracy. BoTNet functions as the backbone network for feature extraction. Subsequently, groundwork is established for enhanced local feature extraction. On this basis, the scholar team devised a Face Attention Augmentation Model (FAAM) to further focus facial recognition on exposed facial features. This model generates a mask image for the unoccluded facial regions. Application of this method markedly improves both the accuracy and precision of facial recognition under occluded settings. Building upon these advancements, the team introduced a specialized joint loss function, L_{face}, to optimize objectives. Integration of this function enhances overall performance in facial recognition tasks. Consequently, these modifications further strengthened model robustness and accelerated convergence rates. Moreover, the authors conducted empirical studies to evaluate algorithmic performance. Experimental validation employed a dataset of approximately 10,000 individuals, totaling 50×10^4 facial images. Results showed recognition accuracy significantly surpassing that of comparative algorithms. Relative to the classical FaceNet approach, this method achieved a 13.9% increase in recognition rates. Data from these experiments demonstrated that the multi-view joint mask occlusion facial recognition design and joint loss function optimization dramatically boosted accuracy in occluded scenarios and reduced the

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prevalence of errors. The research provides effective and practical strategies for addressing real-world occluded facial recognition challenges, and drives technological progress in the domain.

The thesis subsequently introduces a 3D facial recognition method based on ridge point features, proposed by Wang Lijuan and colleagues. Recognizing the complexity of 3D facial recognition under occlusion [6], the scholar team presented an approach leveraging ridge point features in three-dimensional occluded face identification. The method begins with an analysis of the spatial distribution characteristics of ridge points in occluded areas, using a facial ridge point model to detect occlusion locations. Next, three-dimensional shape context (3D Shape Context) is employed to describe the ridge point set features in unoccluded regions. Following this, ridge points from unoccluded regions are matched to corresponding areas in standard face models. Distinct weights are assigned to results in different regions, and an aggregated matching outcome is computed. This dual focus—increasing exploitation of unoccluded facial information and reducing prediction error rates for occluded parts—heightens overall accuracy for facial recognition under occlusion. Experimental trials employed the Bosphorus and UMB-DB 3D facial databases for validation. Findings demonstrated the method's efficacy in detecting and processing occluded regions. The approach sustained high recognition accuracy in 3D occlusion scenarios. In summary, the use of ridge point features combined with a weighted matching strategy emerges as an effective pathway for improving precision in occluded facial recognition.

3.2. Facial recognition under other special conditions

Occasionally, facial recognition tasks arise under atypical conditions. At such times, recognition algorithms developed for occluded faces tend to lose effectiveness. Recognizing this limitation, researchers have refined existing models. Development has progressed toward new algorithms tailored for other scenarios. For instance, recognition is challenged in dimly lit night environments, interior spaces with poor lighting, during subject motion when pose changes continuously, and when facial expressions occur. These circumstances defy the conventional assumption of "ample lighting, consistent pose, and neutral expression." Traditional algorithms—whether designed for clear or occluded faces—experience marked drops in recognition accuracy under these conditions. Consequently, algorithm updates become essential to meet recognition demands in challenging contexts.

A robust multiview approach for recognition under variable lighting and pose, proposed by Wang Lingyue and colleagues [7], warrants attention. The procedural framework is as follows. Initially, to mitigate the impact of varying brightness on original facial imagery, the team utilizes the self-quotient imaging technique for illumination preprocessing. Subsequently, with the goal of restoring faces to a standardized frontal pose, further refinement is applied to the preprocessed images. A generative adversarial network underlies the construction of a multi-pose frontalization model. This model supplies clearer and more comprehensive facial data for expression analysis and extraction. The final stage processes standardized pose images. Recognition of expressions across pose and lighting variation is accomplished by leveraging local binary convolutional neural networks. Experimental results from Wang Lingyue's group affirm improved accuracy and robustness of facial recognition technologies, regardless of pose or illumination.

Additionally, an enhanced facial expression detection algorithm based on YOLOv5, put forth by Lin Shuainan and the team [8-10], demonstrates resolution for model inefficiency and low multiclass expression accuracy found in traditional systems. The workflow is outlined as follows: Backbone network C3 modules and loss functions are substituted to reduce computational overhead. This revision also contributes to greater prediction reliability at boundaries. Ultimately, model

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accuracy is maintained while performance and efficiency are elevated. Experimental validation with real-world datasets further substantiates these findings. Compared to legacy algorithms, the use of this system boosts detection precision by 1.9%. Mean precision average (mPA) increases by 3 percentage points. A noteworthy reduction in model parameters is documented. These results attest to the improvement and practical value of the method over conventional approaches in expression detection.

4. Current challenges and future directions

At present, facial recognition technology has achieved considerable progress, yet many deficiencies and bottlenecks remain. First, at the dataset level, the problem of insufficient diversity often arises. For example, illumination variations are limited, pose differences are not adequately represented, and coverage of age and ethnic groups is insufficient. This results in low generalization capability of datasets. Second, sample bias frequently occurs, with a lack of complex scene data. All of these phenomena lead to inadequate robustness of algorithms. Under cross-scene conditions, sufficient adaptability is lacking. Third, also at the dataset level, two issues prevail. One is the heavy reliance on pre-labeled data and existing computational resources. The other is the high complexity of models and their low interpretability. Therefore, practical applicability remains limited. Notably, recognition accuracy decreases significantly under circumstances involving occlusion, insufficient illumination, variable pose, and complex facial expressions. Finally, in terms of real-world deployment. Improving model accuracy inevitably increases computational complexity. Consequently, this approach presents challenges for real-time processing and mobile deployment. Additionally, facial recognition requires large-scale facial data collection. Thus, potential risks of privacy leakage and related ethical issues arise.

Taken together, facial recognition technology continues to hold substantial potential for development. The thesis proceeds to analyze possible future trends from three perspectives. First, emphasis is placed on advancing multimodal fusion techniques. Developing integrated solutions that combine multiple biometric features—such as facial attributes, voice patterns, and gait signatures—enhances the robustness of recognition systems. The ultimate objective is to achieve accurate recognition. Second, the system is optimized by employing deep learning algorithms. To reduce computational load, the system model is compressed, thereby facilitating application and deployment on mobile platforms. The application of deep learning models in facial recognition can also reduce sample size requirements and diminish the system's dependence on annotated data. Third, enhancing hardware technology promotes the efficient implementation of algorithms, which in turn improves real-time performance on mobile platforms. Overall, the development of facial recognition technology must focus on three key aspects: the breadth of effective information, the depth of algorithms, and the concurrent advancement of both software and hardware. The future of facial recognition technology undoubtedly holds promising prospects.

5. Conclusion

As a significant branch within computer science, facial recognition has drawn considerable attention in recent years. Especially significant is the study of facial recognition under diverse and complex conditions. Enhancing the robustness of facial recognition technology has become a critical factor for achieving breakthroughs in this field. This thesis reviews facial recognition methods under conventional conditions, including 2DPCA and deep learning–based algorithms, as well as methods applied under special conditions such as illumination variation, pose changes, and occlusion. Finally,

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the thesis analyzes current technological bottlenecks and outlines potential future directions.In future research, people should not only focus on algorithmic-level studies but also pay more attention to interdisciplinary applications, such as integrating with various fields like human-computer interaction, psychology, and sociology, to further enhance the wide application of facial recognition technology and its authenticity and reliability. At the same time, issues of data privacy and ethics cannot be ignored, such as how to conduct large-scale data training while ensuring the privacy of individuals is not compromised, and how to achieve healthy and sustainable development in this field. Moreover, with the popularization of smart terminals and the Internet of Things, facial recognition will be applied more extensively in scenarios like smart cities, smart homes, and healthcare. People need to strike a balance between technological progress and real human life, so as to provide the greatest convenience for human life and benefit human society.

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