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COMPARATIVE ANALYSIS OF DENSENET ARCHITECTURES FOR PALMPRINT RECOGNITION ON TONGJI AND IITD DATASETS

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Abstract. Palmprint recognition has emerged as a highly reliable modality in contactless biometric systems. While recent advancements in deep learning have improved accuracy, selecting the optimal network architecture remains a critical challenge. This paper presents a comparative analysis of DenseNet architectures (121, 169, and 201) evaluated on the Tongji (600 classes) and IITD (460 classes) datasets. Experimental results reveal a compelling relationship between network depth and recognition performance. Despite having the fewest parameters (~8.0 million), DenseNet-121 achieved the highest Rank-1 Accuracy of 95.53% (EER 0.14%) on Tongji, and 98.36% (EER 0.47%) on IITD. The findings demonstrate that shallower, parameter-efficient models are optimal and robust for palmprint biometrics.

Keywords: Palmprint Recognition, DenseNet, Biometrics, Deep Learning, Contactless Identification, Feature Extraction, Neural Network Optimization.

Annotatsiya. Kontaktsiz biometrik tizimlarda kaft tasviri izini aniqlash yuqori ishonchli usulga aylanib bormoqda. Chuqur o‘rganishdagi so‘nggi yutuqlar aniqlikni sezilarli darajada oshirsada, optimal tarmoq arxitekturasini tanlash dolzarb muammo bo‘lib qolmoqda. Ushbu maqola Tongji (600 ta sinf) va IITD (460 ta sinf) bazalarida DenseNet (121, 169, 201) arxitekturalarining qiyosiy tahlilini taqdim etadi. Natijalar tarmoq chuqurligi va aniqlik o‘rtasidagi bog‘liqlikni ko‘rsatib, eng kam parametrga (~8.0 mln) ega DenseNet-121 modeli Tongji bazasida 95.53% (EER 0.14%) va IITD bazasida 98.36% (EER 0.47%) eng yuqori natijani qayd etdi. Tadqiqot shuni ko‘rsatadiki, parametr jihatidan samarali, unchalik chuqur bo‘lmagan modellar biometrik aniqlash uchun maqbul va barqarordir.

Kalit so‘zlar: Kaft tasviri izini aniqlash, DenseNet, biometriya, chuqur o‘rganish, kontaktsiz identifikatsiya, xususiyatlarni ajratib olish, neyron tarmoqni optimallashtirish.

Аннотация. Распознавание по отпечаткам ладоней стало высоконадежным методом в бесконтактных биометрических системах. Несмотря на достижения в области глубокого обучения, выбор оптимальной

архитектуры сети остается актуальной задачей. В данной статье представлен сравнительный анализ архитектур DenseNet (121, 169, 201) на базах данных Tongji (600 классов) и IITD (460 классов). Результаты показывают зависимость между глубиной сети и точностью: модель DenseNet-121 с наименьшим числом параметров (~8.0 млн) достигла наивысших результатов — 95.53% (EER 0.14%) на Tongji и 98.36% (EER 0.47%) на IITD. Исследование доказывает, что параметрически эффективные, менее глубокие модели являются наиболее оптимальными и устойчивыми для биометрической идентификации.

Ключевые слова: Распознавание по ладони, DenseNet, биометрия, глубокое обучение, бесконтактная идентификация, извлечение признаков, оптимизация нейронной сети.

INTRODUCTION.

Palmprint recognition has gained significant attention in contactless biometric systems due to its high reliability and rich textural information. While deep learning, particularly Convolutional Neural Networks (CNNs), has revolutionized automated feature extraction, balancing recognition accuracy with computational efficiency remains a critical challenge. Contactless imaging introduces variations that require robust models, yet deploying massive networks on practical edge devices is often computationally prohibitive.

Many contemporary deep learning models trend towards highly complex architectures, operating under the assumption that deeper networks yield better representations. However, in the domain of palmprint recognition—where datasets like Tongji and IITD possess a limited number of samples per class—excessively deep models are highly susceptible to overfitting and performance degradation. Therefore, evaluating architectures that maximize feature reuse while minimizing the parameter burden is essential.

To address this, Dense Convolutional Network (DenseNet) offers a compelling solution by connecting layers in a feed-forward fashion, which alleviates the vanishing-gradient problem and substantially reduces parameter counts. This paper investigates the impact of network depth on recognition accuracy through a comparative analysis of three DenseNet variants: DenseNet-121, DenseNet-169, and DenseNet-201. Evaluated comprehensively on the Tongji (600 classes) and IITD (460 classes) datasets, this study demonstrates that shallower, parameter-efficient architectures can systematically outperform deeper networks, providing a robust solution for contactless palmprint identification.

RELATED WORK.

The evolution of palmprint recognition can be broadly categorized into traditional hand-crafted feature methods and modern deep learning-based

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approaches. Early research predominantly focused on extracting low-level features such as principal lines, wrinkles, and texture matrices. Foundational studies by Zhang et al. [1] and Kong et al. [2] demonstrated the robust discriminative power of palmprints using statistical methods and Gabor filters. Subsequently, various coding-based algorithms, including the Robust Line Orientation Code [3] and Competitive Code [4], were developed to effectively capture palmprint orientations. Furthermore, comprehensive surveys on feature extraction [5] emphasized the limitations of manual feature engineering, particularly its susceptibility to environmental noise and lack of generalization across diverse unconstrained datasets.

In recent years, the paradigm has shifted significantly towards Deep Learning (DL), largely driven by the remarkable feature-extraction capabilities of Convolutional Neural Networks (CNNs). As detailed in a recent comprehensive survey on deep learning in palmprint recognition [6], CNNs have eliminated the need for manual feature crafting by learning hierarchical representations directly from raw image pixels. Early applications of CNNs in biometrics, inspired by architectures like AlexNet and VGG [7], successfully demonstrated high accuracy in offline scenarios. Specifically for palmprints, Zhong and Du [8] utilized CNNs with spatial pyramid pooling, while Dian and Dongmei [9] proposed a completely contactless palmprint recognition framework based on CNNs that significantly outperformed traditional techniques. Additionally, Genovese et al. [10] introduced PalmNet, an unsupervised CNN incorporating Gabor-PCA filters, which proved highly effective for touchless recognition systems.

The transition from contact-based to touchless biometrics introduced new challenges, including scale variations and complex illuminations, heavily relying on datasets such as the IITD and Tongji contactless palmprint databases. Studies utilizing the IITD database [11], [12] have highlighted the necessity for scale-invariant feature extraction. Similarly, multimodal approaches fusing face and palmprint features [13] or exploring spectral domain statistics [14] have been tested on such datasets to achieve zero Equal Error Rate (EER) in strictly controlled scenarios.

Despite these advancements, deploying highly accurate deep learning models often requires significant computational resources. Addressing this, Huang et al. [15] introduced the Dense Convolutional Network (DenseNet), which substantially reduces the number of parameters by connecting layers in a feed-forward manner, ensuring maximum information flow and feature reuse. The integration of DenseNet into palmprint recognition has recently shown promising results. For instance, Zhang et al. [16] integrated spatial and channel features into a DenseNet architecture for color palmprint recognition, achieving exceptional

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accuracy with reduced computational overhead. However, a systematic comparative analysis isolating the impact of specific DenseNet depths (such as DenseNet-121 versus deeper variants like 169 and 201) on standard contactless databases (Tongji and IITD) has not been sufficiently addressed in the literature. This paper bridges that gap by directly comparing these architectures to identify the optimal balance between network depth and biometric performance.

RESEARCH METHODOLOGY.

A) Datasets. This study evaluates model performance using two prominent contactless palmprint databases:

•***Tongji Dataset:*** Contains images from 600 distinct classes with severe intra-class variations (translations, rotations, scale changes).

•***IITD Dataset:*** The version utilized in this study comprises 2,600 images representing 460 distinct classes, captured in a semi-controlled environment.

B) Preprocessing. To eliminate background noise and alignment issues, Region of Interest (ROI) extraction is applied to all raw images. The extracted palm ROIs are uniformly resized to 224×224 pixels and normalized to ensure stable and accelerated network convergence during training.

C) DenseNet Architecture. Standard deep networks often suffer from the vanishing-gradient problem. Dense Convolutional Network (DenseNet) mitigates this by connecting each layer to every subsequent layer in a feed-forward manner. The feature map of the l^{th} layer is defined as:

$$x_l = H_l([x_0, x_1, \ldots, x_{l-1}])$$

where $[x_0, x_1, \ldots, x_{l-1}]$ denotes the concatenation of feature maps from layers 0 to $l-1$, and $H_l(\cdot)$ represents a composite function (BN, ReLU, Conv). This dense connectivity maximizes feature reuse and heavily reduces total parameters. This paper compares three variants:

1. **DenseNet-121:** The most lightweight architecture (~8.0 million parameters).
2. **DenseNet-169:** A moderately deep network (~12.64 million parameters).
3. **DenseNet-201:** The deepest variant evaluated (~18.1 million parameters).

D) Training and Evaluation Metrics. The architectures were trained using categorical cross-entropy loss. To accurately benchmark biometric performance, the models are evaluated based on Rank-1 Accuracy (the percentage of times the correct identity is the top match) and Equal Error Rate (EER) (the point where False Acceptance Rate strictly equals False Rejection Rate).

RESULTS AND DISCUSSION.

To evaluate the impact of network depth on contactless palmprint recognition, three models (DenseNet-121, DenseNet-169, and DenseNet-201) were trained and tested. The performance of these models was primarily measured

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using Rank-1 Accuracy and Equal Error Rate (EER).The initial experiments were conducted on the Tongji dataset, which contains 600 distinct classes. The comparative results are presented in Table 1.

Table 1.

Tongji dataset (600 classes) analysis

Model Name	Number of Parameters	Rank-1 Accuracy	EER (%)
DenseNet-121	**~8.0 mln**	**95.53%**	**0.14%**
DenseNet-169	**~12.64 mln**	**93.95%**	**0.21%**
DenseNet-201	**~18.1 mln**	**95.05%**	**0.24%**

As observed in Table 1, the most lightweight model, DenseNet-121, outperformed the deeper architectures, achieving the highest Rank-1 Accuracy of 95.53% and the lowest EER of 0.14%. Increasing the network depth to 169 and 201 layers resulted in a slight degradation in performance, indicating that excessive parameters do not necessarily correlate with better feature representation in this specific biometric task.To further validate these findings, the models were subsequently evaluated on the IITD dataset, consisting of 460 classes. The results are detailed in Table 2.

Table 2.

IITD dataset (460 classes) analysis

Model Name	Number of Parameters	Rank-1 Accuracy	EER (%)
DenseNet-121	**~8.0 mln**	**98.36%**	**0.47%**
DenseNet-169	**~12.64 mln**	**91.73%**	**3.71%**
DenseNet-201	**~18.1 mln**	**92.96%**	**3.67%**

The results from the IITD dataset strongly reinforce the initial observations. DenseNet-121 again demonstrated superior performance, achieving a remarkable 98.36% accuracy and an EER of 0.47%. Conversely, the deeper DenseNet-169 and DenseNet-201 models exhibited a significant drop in accuracy (down to 91.73% and 92.96%, respectively) and a sharp increase in EER (over 3.6%).

Discussion of the Findings. The empirical results reveal a critical phenomenon in deep learning-based palmprint recognition. While deeper networks are theoretically capable of extracting highly complex features, they require massive amounts of diverse data to optimize their large parameter spaces properly. Contactless palmprint databases like Tongji and IITD possess a limited number of samples per class. Consequently, when highly parameterized models (~12.64 mln and ~18.1 mln parameters) are deployed on these datasets, they rapidly experience overfitting. They memorize the training data rather than

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generalizing the underlying biometric features, leading to higher error rates during the testing phase.In contrast, DenseNet-121, with its relatively compact size (~8.0 mln parameters), provides an optimal architectural balance. Its dense connectivity ensures maximum feature reuse and gradient flow, allowing it to learn robust, discriminative palmprint traits without suffering from the overfitting issues that plague deeper networks. This finding is highly significant for real-world implementations, proving that shallower, computationally efficient models are better suited for accurate and deployable contactless biometric systems.

CONCLUSION.

This paper presented a comprehensive comparative analysis of three distinct DenseNet architectures (DenseNet-121, DenseNet-169, and DenseNet-201) for contactless palmprint recognition. Evaluated on the widely recognized Tongji and IITD datasets, the empirical results clearly demonstrated that increasing network depth does not invariably equate to better performance in this specific biometric domain.

The most lightweight model, DenseNet-121, containing approximately 8.0 million parameters, consistently outperformed its deeper counterparts. It achieved the highest Rank-1 Accuracy of 95.53% and 98.36% on the Tongji and IITD datasets, respectively, while maintaining the lowest Equal Error Rates. The performance degradation observed in the deeper DenseNet-169 and DenseNet-201 models indicates a high susceptibility to overfitting, primarily due to the limited number of samples per class available in standard biometric databases.

The findings of this study conclude that shallower, parameter-efficient architectures like DenseNet-121 provide an optimal balance of high recognition accuracy, robustness, and computational efficiency. As a practical recommendation, future research and development should focus on deploying such optimized, lightweight models on resource-constrained edge devices for real-time biometric authentication. Additionally, further investigations could explore the integration of attention mechanisms to enhance feature extraction without significantly increasing the parameter burden.

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