

Improving Accuracy and Security of Identification by Multimodal Biometric Fusion: An Extensive Analysis

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Abstract - In the modern world, trustworthy and secure identity is essential for a number of uses, such as unlocking personal gadgets and gaining access to secure areas. Conventional techniques, such as PINs and passwords, have shown to be vulnerable to fraud and illegal access. These vulnerabilities have been addressed by the development of biometric authentication, which makes use of an individual's distinct physiological and behavioral characteristics. Unimodal biometric systems concentrate on a single feature, although they frequently face difficulties like noise and spoofing assaults. By merging characteristics from several modalities, multimodal biometric systems provide an answer and improve identification robustness and accuracy. In order to increase identification security and accuracy, this article investigates the combination of hand geometry, palm print, fingerprint, and facial biometrics. Different integration situations and modes of operation for multimodal biometric systems are examined, as well as various fusion methodologies. In summary, the paper ends with implications for biometric systems practitioners, academics, and policymakers as well as a discussion of relevant research topics.

Keywords: Biometrics, Multimodal Biometrics, Fusion Strategies, Identification Security, Authentication Systems.

I. INTRODUCTION

Ensuring dependable and secure identification is crucial for a number of applications, including entering secure locations and gaining access to personal gadgets. Conventional techniques, such as passwords and PINs, have shown to be susceptible to fraud and illegal access. The development of biometric authentication as a strong substitute has addressed these drawbacks. Through the use of distinctive physiological (such as fingerprints, faces, and irises) and behavioral (such as speech) traits that are specific to each individual, biometrics offer a more secure method of identification verification [1].

Numerous biometric systems (unimodal systems) concentrate on a single characteristic; nonetheless, they face

difficulties like noise, unpredictability, and vulnerability to spoof attacks. Multimodal biometric systems, on the other hand, provide higher accuracy and robustness by combining characteristics from several biometric modalities [2]. Through the amalgamation of information from several sources, including hand geometry, palmprint, fingerprint, and face, multimodal systems improve identification precision and surmount constraints linked to unimodal methodologies [3]. Figure (1) shows Biometric identifiers based on hand characteristics.

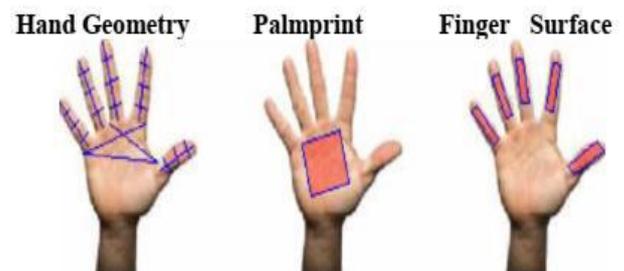


Figure 1: Biometric identifiers based on hand characteristics

There are two main techniques for matching fingerprints: minutiae-based and texture-based. Minutiae-based matching depends on pinpointing particular locations in the fingerprint pattern, like ridge bifurcations and ends. However, texture-based matching examines the fingerprint's overall characteristics and texture in order to identify the fingerprint [4].

Hand geometry parameters are important for biometric identification in addition to fingerprint matching. These characteristics include the length and width of fingers, palm area, and hand shapes. The overall accuracy and dependability of biometric systems are enhanced by the extraction and analysis of these features [5].

This research explores how integrating data from many modalities can improve identification security and accuracy by combining hand geometry, palmprint, fingerprint, and facial biometrics. Multimodal biometric systems provide a solid solution for dependable and secure identity authentication in a range of applications by utilizing the distinctive qualities of each modality.

II. MULTIMODAL BIOMETRICS

Different fusion strategies are used in multimodal biometrics to efficiently integrate information. These tactics function at several levels, such as judgement, matching-score, and feature extraction. Concatenating features derived from two or more sensors is known as feature-extraction fusion. Conversely, fusion occurring at the matching-score level blends the matching scores acquired from several matchers. The decisions from several systems that are approved or rejected are combined at the decision-level through fusion. Due to the wealth of information that is currently available, integrating information early on might be beneficial, but it can also present problems like growing databases and incompatibilities between various modalities [6].

For example, a lack of information, such as the incompatibility between face Eigen values and fingerprint minutiae points, may result in inflexible fusion at the decision level. Therefore, as it is simpler to obtain and combine scores, fusion at the matching-score level is frequently chosen [7].

Systems for multimodal biometrics can be built to function in a variety of integration scenarios. In these cases, outputs from various sensors, instances, samples, representations, biometric features, and matching algorithms are combined. For recognition, for instance, different examples of the same biometric characteristic, such

photographs of the left and right iris, might be merged. Similar to this, to increase accuracy, various representations and matching algorithms for the same biometric attribute can be mixed. Examples of this include texture-based and minutiae-based fingerprint matchers [8].

Moreover, there are three modes of operation for multimodal biometric systems: serial, parallel, and hierarchical. The output of one modality is linked to another in the serial mode, allowing for the sequential and distinct acquisition of data from various modalities. In the parallel mode, distinct modalities' worth of data is simultaneously gathered for identification. A blend of serial and parallel modes is used in the hierarchical mode, enabling a more adaptable and effective merging of data across modalities [9].

III. RELATED WORKS

An overview of different research projects in the field of multi-modal biometric recognition is given in the table. With the integration of different biometric modalities, the field of biometrics which focuses on identifying individuals based on distinctive physiological or behavioral characteristics has made great progress. Acknowledging the significance of augmenting security and precision in authentication systems, scholars have investigated several approaches to leverage the aggregate potency of distinct biometric characteristics.

Table 1: Related Works Analysis

Researcher	Problem	Method	Results	Strength Points	Limitations
Alay et al. [10]	Multi-modal biometric human recognition using face, finger vein, and iris biometrics	Deep learning algorithm based on convolutional neural networks (CNNs), specifically VGG-16 model	Achieved accuracy of 100% with feature-level fusion and 99.39% with score-level fusion	High accuracy rates, effective use of CNNs, feature-level fusion improved results	Limited to specific biometric traits, dataset used might not represent real-world scenarios
Garg et al. [11]	Increasing recognition security through multi-modal biometric fusion using speech, iris, and signature biometrics	Feature extraction techniques including Mel-frequency spectral coefficients, Scale Invariant Feature Transform (SIFT), 2DPCA	Accuracy range of 96–98%	High accuracy, use of multiple biometric traits, utilization of genetic algorithm for feature optimization	Specific to speech, iris, and signature modalities, might not generalize to other biometric traits
Sengar et al. [12]	Utilizing palm print and fingerprint data for secure authentication	Multi-modal biometrics, focus on palm print and fingerprint data	Achieved accuracy rate of 97%	High accuracy rate, utilization of rich biometric information from palms and	Limited to palm print and fingerprint modalities, might not generalize to other biometric traits

				fingerprints	
Vinothkanna et al. [13]	Employing fuzzy vault for recognition of palm prints, hand veins, and fingerprints	Pre-processing techniques, feature extraction, creation of fuzzy vault	Improved recognition with 98.5% accuracy	Utilization of fuzzy vault, combination of multiple biometric traits, effective pre-processing techniques	Limited to specific pre-processing and feature extraction methods, might require further testing in real-world scenarios
Mahmoud et al. [14]	Verification of identity through iris and facial features using multi-modal biometrics	Feature extraction using R-HOG, feature-level fusion using deep belief network	Reduced equal error rate (EER) and up to 99% recognition accuracy	Utilization of feature-level fusion, improved recognition accuracy, reduced fusion time	Specific to iris and facial features, might not generalize to other biometric traits
Xinman Zhang et al. [15]	Development of a multi-modal biometric system for Android using voice and face recognition	Improved LBP coding-based feature extraction, enhanced VAD technique, adaptive fusion method	Successful deployment of identity identification in various scenarios with high-security applications	Improved feature extraction and fusion techniques, suitability for Android-based systems	Specific to voice and face recognition, might not generalize to other biometric traits
Abderrahmane et al. [16]	Proposal of a weighted quasi-arithmetic mean (WQAM) method for score-level fusion in biometric recognition systems	Calculation of WQAMs using various trigonometric functions	Improved recognition accuracy without requiring a learning process	Innovative fusion method, no need for learning process, utilization of weighted quasi-arithmetic means	Limited to score-level fusion, might not be applicable to all biometric recognition systems
Rane and Bhadade [17]	Development of a multi-modal biometric authentication system using face and palm print recognition	Matching score fusion technique based on t-norm, utilization of various face and palm print databases	Achieved GAR of 99.7% at FAR of 0.1% and GAR of 99.2% at FAR of 0.01%	High accuracy rates, utilization of multiple biometric traits, improvement over previous methods	Limited to specific biometric traits, might require further evaluation in real-world scenarios
Srivastava [18]	Enhancement of multi-modal biometric cryptography system using individual finger impression, retina, and finger vein biometrics	Score-level combination strategy, utilization of DNN for orders, RSA for encryption, SIFT for feature extraction	Improvement in performance by 98.9% with GAR, 98.5% with accuracy, and 0.05% with FAR	Increased security and performance, utilization of multiple biometric traits, enhancement over uni-modal systems	Specific to fingerprint, retina, and finger vein modalities, might not generalize to other biometric traits
Devi and Rao [19]	Development of decision-level fusion systems for multi-	Utilization of wavelet sub-bands, nearest neighbor	Maximum increase in average recognition rates,	Effective fusion techniques, improved	Limited to decision-level fusion, might not generalize to all

	modal biometric recognition	classifier, balanced qualified majority fusion	improved fusion methods	recognition rates, utilization of wavelet sub-bands for feature extraction	multi-modal biometric recognition scenarios
Iloanusi and Ejiogu [20]	Classification of gender from fingerprints using deep learning convolutional neural networks	CNN architecture for gender classification from fingerprints	Improved gender classification accuracy rates	Utilization of deep learning techniques, effective classification of gender from fingerprints	Limited to gender classification from fingerprints, might require further evaluation in diverse scenarios
Zhou et al. [21]	Proposal of a hybrid fusion method for multi-modal biometric systems	Utilization of unique weighting vote approach, enhanced feature fusion algorithm	Superior precision and robustness in multi-modal biometric systems	Effective fusion technique, improved accuracy rates, utilization of hybrid approach	Limited to specific fusion methods, might not generalize to all multi-modal biometric systems
Chang et al. [22]	Introduction of BIOFUSE strategy for multi-biometric fusion in cryptosystems	Implementation of fuzzy commitments and fuzzy vaults using format-preserving encryption	High recognition performance with increased security	Enhanced security through BIOFUSE strategy, improved recognition performance	Limited to cryptographic applications, might not be directly applicable to all biometric recognition scenarios
Wajid et al. [23]	Development of a multi-modal biometric method based on palm and fingerprint recognition	Utilization of UPEK fingerprint and IITD palm-print databases	Achieved FAR of 2.0%, FRR of 2.25%, and TSR of 98.75% with a total matching time of 1.90 seconds	High accuracy rates, utilization of multiple biometric traits, efficient matching time	Limited to palm and fingerprint recognition, might not generalize to other biometric traits
Yadav [24]	Proposal of a multi-modal human identification model based on deep learning algorithms	Utilization of iris, fingerprint, and handwritten signatures as biometric modalities	Achieved accuracy of 99.11% with feature-level fusion and 99.51% with score-level fusion	Utilization of deep learning algorithms, high recognition accuracy, effective fusion techniques	Limited to specific biometric traits, might not generalize to all multi-modal biometric recognition scenarios
Kamlaskar and Abhyankar [25]	Implementation of canonical correlation analysis (CCA) for feature-level fusion of iris and fingerprint biometrics	Utilization of CCA for maximally correlated feature extraction from iris and fingerprint feature sets	Achieved effective multi-modal recognition with reduced feature size and computational complexity	Utilization of CCA for feature fusion, improved recognition accuracy, reduced computational complexity	Limited to iris and fingerprint modalities, might require further evaluation in diverse scenarios
Kumar et al. [26]	Integration of face and fingerprint recognition systems for improved	Utilization of whale optimization algorithm and maximally stable external regions for	Achieved average true positive rate of 99.8% and accuracy of 99.6%	Improved recognition performance, utilization of feature fusion techniques,	Limited to face and fingerprint recognition, might not generalize to

	biometric fusion	feature extraction		high accuracy rates	other biometric traits
Vijayakumar et al. [27]	Construction of a multi-modal biometric user identification model using CNN deep learning for feature extraction	Utilization of CNN deep learning for accurate feature extraction	Accuracy and error-free identification of individuals	Utilization of deep learning for feature extraction, inclusion of palm prints in multi-modal biometric model	Limited to specific biometric traits, might require further evaluation in diverse scenarios
Arjun and Prakash et al. [28]	Development of a hybrid model for multi-modal biometric recognition using face and finger vein biometrics	Utilization of decision level and feature level fusion, incorporation of face and finger vein modalities	Higher recognition rate compared to unimodal systems	Effective fusion of face and finger vein modalities, improved recognition performance	Limited to specific fusion techniques, might not generalize to all multi-modal biometric recognition scenarios
Channegowda et al. [29]	Design of multi-modal biometric models for increased accuracy in person recognition	Utilization of deep learning neural network models, multi-level feature fusion	Positive results in recognition accuracy and performance	Effective utilization of deep learning techniques, improved recognition accuracy	Limited to specific datasets and deep learning models, might require further testing in real-world scenarios
Sarangi et al. [30]	Improvement of ear biometrics recognition using profile face and ear modalities	Combination of local feature descriptors, feature fusion at multiple levels	Outperformed individual modalities and existing techniques in terms of performance	Utilization of deep features and fusion techniques, improvement over existing methods	Limited to ear and face modalities, might require further evaluation in diverse scenarios
Purohit and Ajmera [31]	Proposal of an efficient feature-level fusion technique for multi-modal biometric recognition	Utilization of region-growing method, feature extraction, better fusion techniques	Improved recognition performance with efficient feature fusion	Effective feature fusion techniques, utilization of optimization strategies for feature selection	Limited to specific fusion techniques and biometric modalities, might not generalize to all scenarios
Jaswal and Poonia [32]	Development of a multi-modal biometric approach for identifying individuals using finger knuckle and palm images	Utilization of LOP encoding, non-decimated quaternion wavelet, ensemble classifier	Improved recognition and verification performance	Effective feature extraction and fusion techniques, improved recognition and verification accuracy	Limited to specific biometric traits, might require further evaluation in diverse scenarios
Tharewal et al. [33]	Creation of fusion deep-learning classification algorithms for multi-modal biometric recognition	Utilization of deep learning techniques, fusion at score-level	Achieved accuracy of 99.25% with score-level fusion	Effective fusion of 3D ear and face modalities, improvement over existing methods	Limited to specific fusion techniques and datasets, might not generalize to all multi-modal biometric

					recognition scenarios
Mohammed et al. [34]	Exploration of multi-biometric fusion for individual identification using feature-level fusion	Introduction of Dis-Eigen algorithm, feature-fusion architecture	Feature-level fusion multi-biometric individual detection rate of 93.70%	Improved accuracy in individual identification, utilization of feature-level fusion techniques	Limited to specific fusion techniques and datasets, might require further testing in diverse scenarios
Joseph et al. [35]	Development of a multi-modal biometric system for person recognition using face and fingerprint identification	Utilization of ORB algorithm, Convolutional Neural Network (CNN), score-level fusion	Encouraging results in person recognition system	Effective utilization of feature fusion techniques, improvement in recognition performance	Limited to specific fusion techniques and datasets, might not generalize to all multi-modal biometric recognition scenarios
Banati et al. [36]	Implementation of a score-level fusion strategy for multi-modal biometric recognition	Utilization of face, palm print, and fingerprint modalities	Authentication rate of 95.08%	Higher authentication rate compared to individual modalities, effective fusion strategy	Limited to specific fusion techniques and datasets, might not generalize to all scenarios

IV. DISCUSSION

The research findings are thoroughly summarized in the discussion, which emphasizes the importance of multi-modal biometric recognition breakthroughs. Methodological insights highlight the complexity and originality of the area by revealing the wide range of approaches used, such as CNN integration, fusion techniques, and deep learning algorithms. Performance evaluation indicators that highlight the potential of multi-modal biometrics to improve security include accuracy rates and error rates, providing quantitative benchmarks for assessing system efficacy.

The research' use of deep learning and efficient fusion techniques, which enhance recognition performance, are among its strong points. Nonetheless, intrinsic constraints like dependence on particular modalities or datasets emphasize the necessity for more investigation to tackle issues related to scalability and resilience. Practical implementation also requires careful consideration of computing complexity and real-world usefulness.

The research findings have implications for practitioners, researchers, and policymakers working on the creation of biometric systems. Understanding the benefits, drawbacks, and implications helps researchers make well-informed decisions and directs their future work. Future possibilities could include utilizing developing technology, investigating novel fusion strategies, and resolving identified limits in order

to improve system performance in a variety of real-world circumstances.

V. CONCLUSION

This research concludes by highlighting the role that multimodal biometric recognition plays in improving the security and precision of identification. By merging different biometric modalities and fusion techniques, multimodal systems provide reliable authentication solutions for a range of applications. The thorough analysis of relevant research initiatives highlights the developments in the field and points out areas that require more study and development. Through the utilization of deep learning techniques, effective fusion methods, and innovative methodologies, scientists can keep improving the dependability and efficiency of multimodal biometric systems. In the end, the information offered in this work has consequences for the advancement of biometric systems, directing future lines of inquiry and useful applications.

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