

A Hybrid Approach for Face Morphing Detection

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Abstract

Background: In biometrics, one of the most popular study topics is the detection of face morphing attacks. However, because present methods are unable to capture significant feature changes, they are unable to strike the correct balance between accuracy and complexity. Survey investigation and analysis have shown that the existing method of face morphing detection take a bit longer time to detect the image attack due to the high computation required by facial feature extraction approaches. Conversely, further study is needed to develop a model to enhance the computational time and accuracy of the current face morphing recognition methods. The paper developed a hybrid model for face morphing detection. The FERET database was created to aid in the evaluation and development of algorithms. Local Binary Pattern (LBP) was used as feature extraction algorithm and Residue Number System (RNS) was introduced to reduce the lengthy computational time of LBP during the extraction of images. The classification accuracy of 98% was achieved for the FERET database, while an accuracy of 96% was achieved for the FRGCv2 database. An average training time of 0.0532seconds was recorded for the FERET database, while an average training time of 0.0582seconds was achieved for the FRGCv2 database. The study concluded that the high dimensionality of LBP was well reduced and optimized by the RNS algorithm, which improved the performance of face morphing recognition.

Keywords: FERET database, FRGCv2 database, local binary pattern, residue number system.

1. Introduction

One common topic of biometrics research is the detection of face morphing attacks. However, due to their inability to capture significant feature differences, existing approaches find it difficult to strike the correct balance between accuracy and complexity. Morphing attacks, which alter the biometric reference in an identity paper, can affect biometric systems. This kind of attack presents a significant issue for systems that rely on identity documents, such as access control or border security. While research on face morphing assault detection is rapidly growing, there are no many publicly available datasets covering a wide range of attack kinds (Denis, 2019). Attacks involving face morphing have serious repercussions, much like acts of terrorism. Such attacks reportedly succeeded in fooling the border control system to obtain illegal authorizations (Muhammad et al., 2024). As a result, in the last several years, this issue has drawn significant attention in the field of research. Recently, a number of techniques for identifying face-morphing attacks have been introduced (Jayashalini & Priyadharshini, 2019).

It is commonly known that the Face Recognition System (FRS) has security flaws (Scherhag, Rathgeb, Merkle, & Busch, 2020). Research indicates that contemporary systems can adapt to small adjustments (Pavel & Marcel, 2019). Morphing assaults are the most damaging kind of attack and rely on changed facial images, FRS is more susceptible to relevant attacks. The level of security risk posed by morphing assaults has been demonstrated, as initially noted by the scientific community in (Ferrara, Franco & Maltoni, 2018). In an attempt to put a stop to them, security agencies are prompted to pursue legal action. As a result, morphing attack detection (MAD) is currently being extensively studied by researchers, many of whom are offering various solutions to the issue (Mary et al., 2022).

Researchers generally agree that morphing attack detection is still a very difficult and unsolved topic despite several attempts as reported in (Korshunov & Marcel, 2018; Scherhag et al., 2020). This is simply a reflection of the fact that identification of morphing attacks remains essentially an open topic. Moreover, there are numerous naturally occurring causes of face morphing detection unreliability, such as classification errors, timing errors, and security problems. These therefore demand the requirement for reliability measures. While many studies highlight the potential for high security and lower computational complexity, the specific implementation details and comparative effectiveness of these schemes remain areas for further research (Samson et al., 2024). Investigation and analysis have shown that the existing methods of face morphing detection is time consuming in detecting the image attack due to the high computation time required by facial feature extraction approaches (Iman & Bahja, 2023). Conversely, further study is needed to develop a model to enhance the computational time and accuracy of the current face morphing recognition methods. Therefore, few facial feature extraction techniques have been recommended for enhancing the time efficiency and accuracy of face morphing recognition systems (Stephanie & Cecilia, 2022).

Generally, time efficiency and accuracy in local binary pattern models arise due to computational processing and feature vectors. Feature vector used to feed an adequate classifier or discriminative scheme to decide the faceless (a measure to determine the similarity of an object to a human face) of the input image or the identity of the input face in case of facial expression recognition. This always causes feature vector redundancy among the classes during the feature extraction processes. Feature vector redundancy can be split by introducing the Residue Number System (RNS) during the feature vector computation processes (Adigun, et al., 2024). Considerable research efforts have been focused on the development of techniques for face morphing detection. It was observed that few of the several researches on face morphing recognition has offered extensive time efficient and accuracy for face morphing recognition systems. Therefore, there are many open issues in developing or improving techniques for face morphing recognition. This research paper aims at providing an enhanced Local Binary Pattern (LBP) with RNS for real-time morphing recognition. RNS was employed because it has fault-tolerant, high speed and error control scheme property called Redundant Residue Number System (RRNS).

2. Related works

Vanitha, Tejavaradhan, Abhishek and Laya (2024) studied a survey regarding face morphing attack detection. The work focuses on how susceptible these systems are to morphing attacks, and it suggests a strong detection mechanism that can adapt to changes in age, lighting, and the presence of headgear and eyes. The suggested method makes use of a deep learning-based feature extractor and classifier. Furthermore, to improve the detection outcomes, feature combination and picture enhancement approaches are introduced. To assess how well the proposed methods work, an accessible dataset is produced. Eight different databases are used in the production of morphs in order to

cover a broad variety of variants. The results obtained from multiple experimental setups indicate that the proposed methodology yields good accuracy. Both the training and testing time need little adjustment

Adigun et al. (2024) improved local binary pattern method with the Chinese Remainder Theorem for facial identification. User identification and authentication were carried out using Local Binary Pattern (LBP), one of the techniques for feature extraction, and Chicken Swarm Optimization (CSO), one of the techniques for feature selection. By creating an Enhanced Local Binary Pattern (ELBP), the Chinese Remainder Theorem (CRT) was utilized to shorten the computation time. Specifically for this research, the Michael Olugbenga Banji Abolarinwa (MOBA) database was developed. Two hundred individuals had their 600 frontal facial photographs taken, each containing three pictures. For training, 360 photos were used, and for testing, 240 images. To execute the simulation, MATLAB (R2016a) was utilized. We listed the amount of time it took to identify the facial photos when ELBP and CSO were combined, as well as when LBP and CSO were combined. The LBP-CSO successfully recognized faces in 119.10 seconds at 0.80 thresholds with a false-positive rate (FPR) of 11.67%, sensitivity (SEN) of 92.78%, specificity (SPEC) of 88.33%, precision (PREC) of 95.98%, and accuracy of 91.67%. ELBP-CSO performed the extraction in 79.16 seconds with an FPR of 5.00%, SEN of 95.00%, SPEC of 95.00%, PREC of 98.28%, and accuracy of 95.00%. The average time for LBP-CSO was found to be 119.10 seconds, while the average time for ELBP-CSO was 79.16 seconds. In conclusion, the use of LBP enhancement with CRT is justified by the performance of CSO-ELBP. More improvement is needed in terms of accuracy and computational time

Iman & Khudiar (2023) suggested employing texturing techniques for the generation and detection of face morphing. Three phases make up this work. The first entails making morphing faces by merging landmarks found through edge detection with morphing created by morphing itself. In the second step, images are sent to a face recognition system, which extracts features using an LBP. Texturing techniques are used in the third stage to differentiate between actual images and image morphs. For the AMSL dataset, the recommended method yielded an accuracy of 80% and required 1.462 seconds for training. The findings indicate that the morph attack detection system's speed and accuracy fall short of operational requirements, hence more improvement is needed to improve the performance of the detection system.

Raghavendra & Guoqiang (2022) proposed a single image-based morphing attack detection (S-MAD) framework based on multimodal regions such the mouth, nose, and eyes. Two distinct feature extraction techniques, such as Local Binary Features (LBP) and Binarized Statistical Image Features (BSIF), are applied to each of these regions after they have been processed using a representation in color scale-space. The LBP method's training time for face morphing attack detection is 0.56 sec, compared to 0.72 sec for the BSIF approach. This study demonstrated that different approaches could be applied in subsequent research to reduce the computation times for the BSIF and the LBP in order to identify face morphing attacks. The proposed work will introduce RNS to LBP to reduce the computational time

Ulrich et al. (2022) proposed a novel approach for morphed face picture detection. The work employs Local Binary Pattern (LBP) for feature extraction and random forest for the classifier. A comparison of the angles of discrepancies between passport images and authentic images yields a D-EER of 32.7%. A reduced error rate is achieved by combining both techniques.

Table 1: Review of Related works

Paper	Authors/ Year	Title	Improvement	Limitation
1	Vanitha, Tejavardhan, Abhishek and Laya (2024)	a survey on face-morphing attack detection.	Discusses the vulnerability of morphing attacks and suggests a strong detection method that can handle changes in age, lighting, and the existence of headgear and eyes.	The study finds that detection models trained on low variance databases have difficulties when dealing with photos that are manually created using advanced morphing techniques to provide high-quality morphed outputs.
2	Adigun et.al (2024)	Improved local binary pattern method with the Chinese Remainder Theorem for facial identification	Because of its parallelism and simultaneous operation, the suggested technique improves recognition performance while reducing computational complexity.	It was discovered that the suggested Algorithm was insufficient for application in actual industrial settings.
3	Iman & Khudiar (2023)	Producing and Identifying Face Morphing Through Texture Methods.	The approach produced useful outcomes that demonstrated how to decrease morphing attacks.	It was discovered that the morph attack detection accuracy was not up to operational requirements, which has an impact on the system's performance accuracy.
4	Raghavendra & Guoqiang (2022)	A framework for morphing attack detection (S-MAD) based on multimodal regions in a single image	Explains how face morphing attacks can affect facial recognition systems, highlighting the need of morphing attack detection (MAD) tools	Raises concerns about overfitting in MAD algorithms

			for improving system security.	
5	Ulrich, Dhanesh, Marta Gomez & Christoph (2022)	A new method for identifying altered facial pictures.	A reduced error rate is achieved by combining both techniques.	The abstract does not explicitly address the generalizability of findings beyond specific experimental conditions, raising questions about the broader applicability of the results to real-world scenarios.

3. Methodology

3.1 Research Design

An experimental research method was adopted for this research process. The rationale for this is described in the next section. Each methodology stage is logically explained. This study mainly focuses on proposing an enhanced face morphing recognition model using a Local Binary Pattern (LBP) with a Residue Number System (RNS). To overcome the challenges in the existing system as stated in the previous chapter. The general research methods are outlined in Figure1.

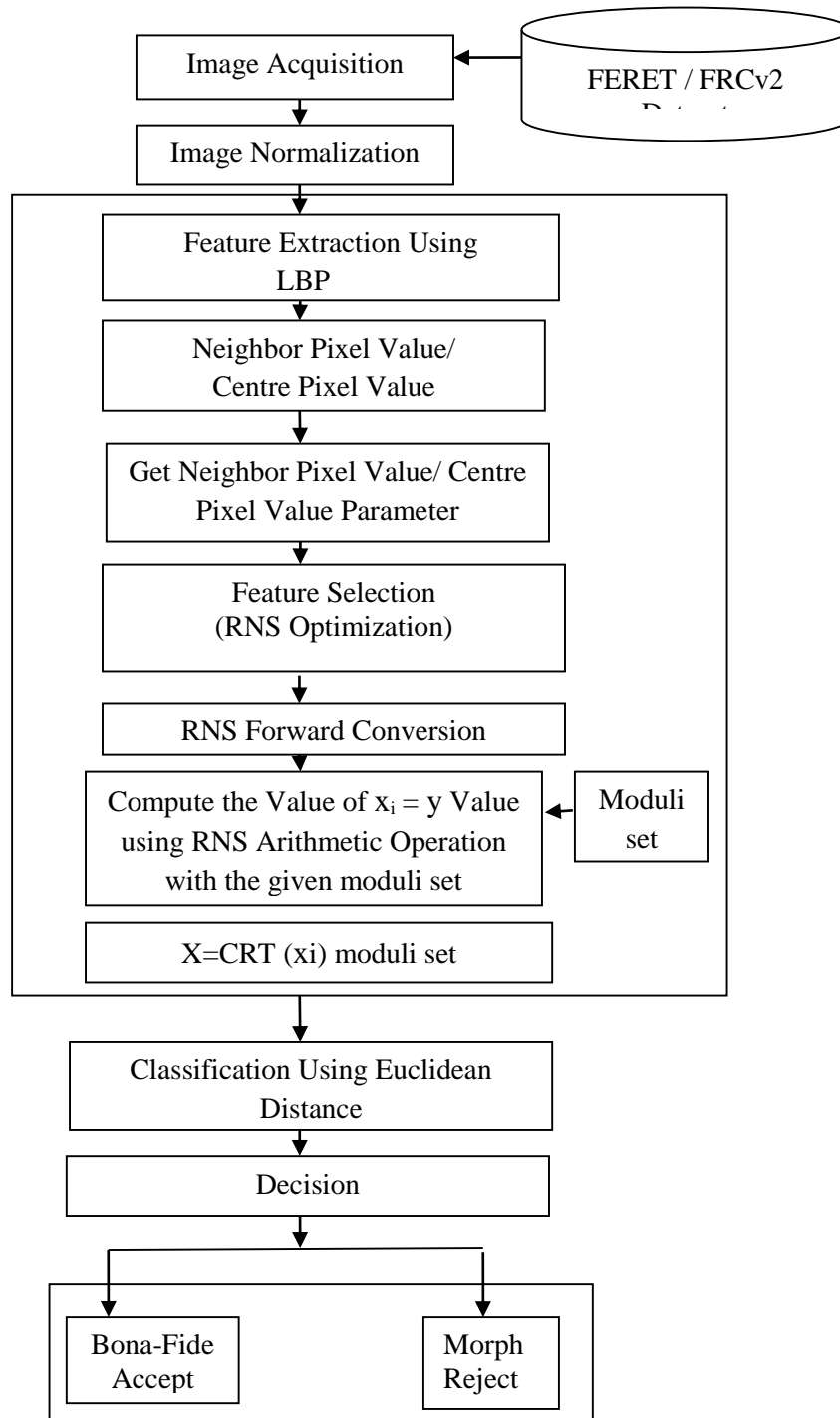


Figure 1: Blocked Diagram of the Local Binary Pattern and RNS Approach for Face Morphing Recognition System

3.2 Image Acquisition

The FERET database was created to aid in the evaluation and development of algorithms. The FERET database is a dataset for face morphing recognition. It contains 11,338 colour images of size 512×768 pixels captured in a semi-controlled environment with 13 different poses from 994 subjects. Researchers can utilize the FERET database as a standard face image database to create different algorithms and report findings. In this work, 100 face images were selected from the FERET database and used for training and testing at the rate of 60 and 40 instances respectively as shown in Figure 2.



Figure 2: Sample Images from the FERET Database

FRGCv2 database

FRGCv2 database is a dataset for face morphing recognition. There are 1,440 genuine and 964 morphing photos in it. The pictures were from various illumination variations, with and without eyeglasses and in a variety of facial expression modes (normal, happy, surprise, flabbergasted, and glint). 60 images were used for training and 40 for testing. Figure 5 show some of FRGCv2 dataset use for training the database.



Figure 3: Sample Images from the FRGCv2 Database

3.3 Data Preprocessing

Before the feature extraction, face images in the dataset should be normalized and pre-processed to the face recognition system. Conversely, the purpose of normalizing images is to attain uniformity in dynamic range to prevent weakness in images. Figure 2 shows the steps to describe the face normalization stages in this work.

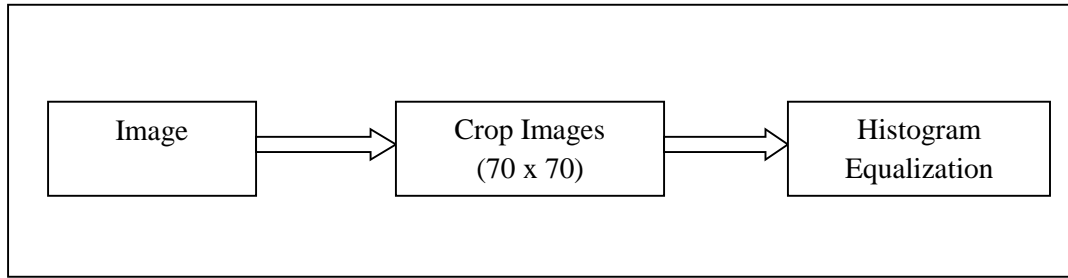


Figure 4: Stages of Face Preprocessing

Subsequently, the normalized region is cropped to 70×70 pixels to ensure that the detection algorithm is only applied to the facial region. Finally, the cropped face part is converted to a gray scale image. The technique of histogram equalization uses the histogram of an image to modify the contrast.

3.4 Feature extraction using Existing Local Binary Pattern

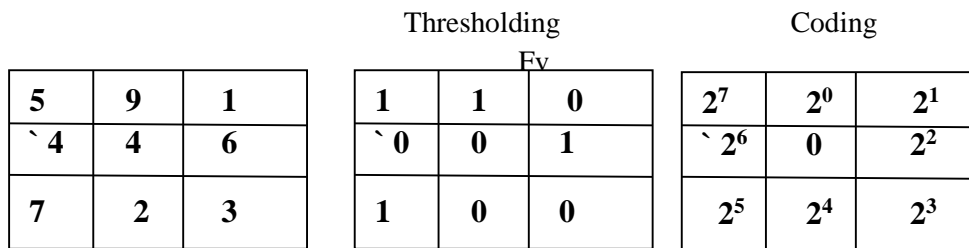
The LBP operator converts the pixels of the provided image into a sequence of 1 or 0 value. However, given a pixel position (l_c, l_n) , an ordered set of binary comparisons of pixel intensities between the center and surrounding pixels is known as an LBP. The mathematical formulation of LBP is given below as

$$LBP = \sum_{n=0}^7 (l_n - l_c) 2^n \dots \dots \dots 1$$

where:

l_c = Centre Pixel Value

l_n = Neighbor Pixel Value



$$2^7 + 2^0 + 2^2 + 2^5 = 165$$

Figure 5. Computation of LBP Operator

The main problem of the local binary operator is that it costs a little space around a 3×3 matrix. Hence, for high dimensional features, the feature can be reduced when introducing the feature of the Residue Number System with respect to the moduli set of $\{2^{n+1}-1, 2^n, 2^n-1\}$ to the local binary operator. Thus, it will be possible to perform texture analysis of images of different sizes more effectively.

3.5 Formulation of Local Binary Pattern and Residue Number System

The LBP-RNS combines features of LBP with the RNS technique to perform feature extraction for face morphing detection. This algorithm aims to reduce the high dimensionality feature of LBP to a low dimensionality feature and improve the computational time of LBP during the feature extraction process. The following is a detailed description, including mathematical formulations for the enhanced Local Binary Pattern model.

$$LBP = \sum_{n=0s}^{p-1} (ln - lc)2n \text{ mod RNS } [2n + 1, 2n, 2n - 1] \dots \dots \dots 2$$

Where $ln - lc$ denotes the neighbour pixel and centre pixel, p is the number of neighbouring pixels and $0s$ is the sign function (1 if the number is non-negative, otherwise 0).

RNS is based on the congruence relation, which is described in terms of relatively prime moduli set $\{m1, m2, \dots mn\}$ that is, greatest common divisor $gcd(mi, mj) = 1$ for $(i \neq j)$. A weighted number X can be given as:

$$X = (x1, x2 \dots xn), \text{ where: } xi = X \text{ mod } mi = |X|pi, 0 \leq xi < \dots \dots \dots 3$$

The most effective speed-efficient algorithm for face detection at low speed was modified by combining RNS with the original LBP algorithm to reduce the high dimension feature of LBP to low dimension feature.

128	1	0
0	0	4
32	0	0

7	4	3
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Mod =

$$|128|_7 = 2 \quad |1|_7 = 1 \quad |0|_7 = 0$$

$$|0|_4 = 0 \quad |0|_4 = 0 \quad |4|_4 = 1$$

$$|34|_3 = 2 \quad |0|_3 = 0 \quad |0|_3 = 0$$

2	1	0
0	0	1
2	0	0

$$= 2 + 1 + 1 + 2 = 6$$

The integration LBP operator converts the provided image's pixels into a series of 1 or 0 values, by comparing the values of every pixel in the 3x3 neighborhood surrounding a chosen image pixel. For every pixel in the image, a label is made with the generated binary number on it: 110001100 is converted to 165. Introduction of RNS to LBP reduces the feature dimension from 165 to 6 and provides a robust computational process.

Algorithm 2: LBP- RNS Algorithm (Pseudocode)

Step 1: Set L_c which corresponds to the gray value of the centre pixel

Step 2: Set L_n as the gray values of the n which is one of the neighbour pixels

step 3: Let L_n and L_c denotes the neighbour pixel and centre pixel, p is the number of neighbouring pixels and O_s is the sign function (1 if the number is non – negative, otherwise 0)
 $x = (x_1, x_2 \dots x_n)$ where: $x_i = x \bmod m_i = |x|p_i, 0 \leq x_i <$

step 4: let $P1 = L_n - L_c (2n) \text{equation (1) mod (rns)} \{2n + 1 - 1, 2n, 2n - 1\} \text{eq (2)}$

since L_c and L_n are coprime. Then this study formulate an equation for enhance LBP where $L_n - L_c$ denotes the neighbor pixel and centre pixel, p is the number of neighbouring pixels and O_s is the sign function (1 if the number is non – negative, otherwise 0)

moduli set $\{m_1, m_2, \dots m_n\}$ that is, greatest common divisor $\text{gcd}(m_i, m_j) = 1$ for $(i \neq j)$

Step 5: Output selected LBP featur

3. 6. Classification

The Euclidean distance classifier is utilized to identify frontal faces. This classifier was chosen because it has strong reputations in statistical theory and has proven to be successful in a variety of detection tasks in computer vision. The conventional (straight line) distance between any two places in Euclidean space is known as the Euclidean distance. We'll use the Euclidean distance classifier, one of the most well-known and straightforward techniques for categorizing images.

4. Results and Discussion

For the implementation of a LBP-RNS for face morphing recognition, the Local Binary Pattern (LBP) was improved by introducing a Residue Number System (RNS) for feature reduction. This work computes the LBP representation of each face image in the dataset. Face morphing recognition and recognition algorithms were implemented in an application with an intuitive graphical user interface (GUI) to help in the training and testing stages as shown in Figure 6

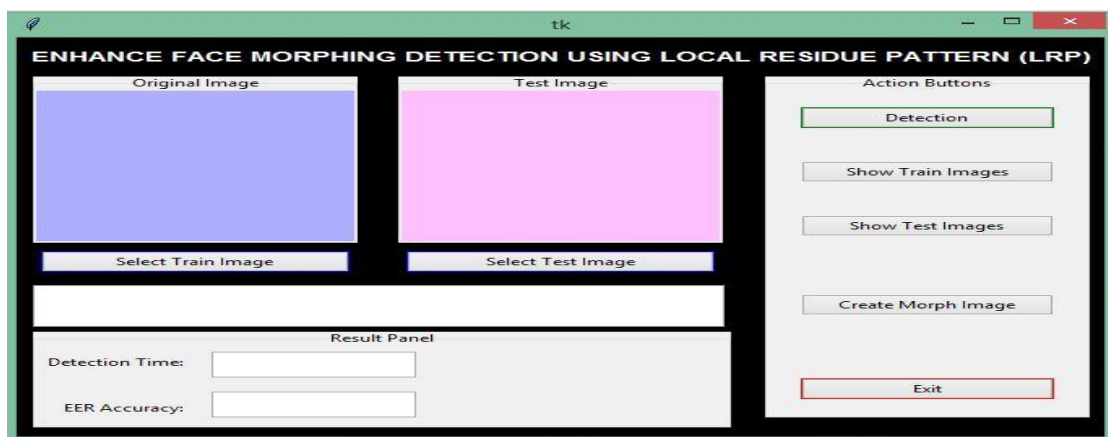


Figure: 6 GUI of the Developed System

Figure 6 differentiates the sections: select train image selection, show train image and texting image (right-side), create morph image (right-side), recognition time and EER accuracy at (centre-region). The test image area is operational as soon as the training files are received. The result obtainable in Table 1 shows the performance of the LBP-RNS feature extraction training time. 40 datasets were used for testing. The develop technique is subject to a series of tests to affirm its enhancement in terms of time taken and accuracy error equal rate. In addition, the training time of the developed technique is recorded and compared to the existing literature. The developed technique has been trained on both FERET and FRGCv2 datasets and it indicates that the developed technique has better performance for training time on different images as shown in Table2 which illustrates the training time measured in seconds together with images.

Table 2: Test of Local Residue Pattern Framework on FERET and FRGCv2 Dataset

Images	Training Sample (LRP Model on FERET Dataset)	Training Sample (LRP Model on FRGCv2 dataset)
1	0.0532sec	0.0582sec
2	0.0573sec	0.0588sec
3	0.0581sec	0.0592sec
4	0.0610sec	0.0631sec
5	0.0635sec	0.0644sec
6	0.0657sec	0.0651sec
7	0.0711sec	0.0736sec
8	0.0732sec	0.0744sec
9	0.0741sec	0.0752sec
10	0.0781sec	0.0783sec
11	0.0791sec	0.0710sec
12	0.08132sec	0.08721sec
13	0.08241sec	0.08762sec
14	0.08572sec	0.08811sec
15	0.08632sec	0.08924sec
16	0.08741sec	0.08973sec
17	0.08811sec	0.089810sec
18	0.08835sec	0.09240sec
19	0.08910sec	0.09421sec
20	0.09100se	0.09531sec

Furthermore, Table 2: shows the training time for each image that was investigated and findings show that the developed LRP framework generates less time on the FERET dataset than the FRGCv2 dataset. In comparison with existing literature, Table 3 shows that the LRP-based face morphing recognition framework outperforms the existing state-of-art schemes in terms of reduced LBP training time.

Table 3: Comparing the LRP Technique with Related Studies

Author (Years)	Title	Training Time (seconds) FERET Database	Training Time (Seconds) FRGCv2 Database
Wandzik, Kaeding and Gercia (2020)	Apply Local Binary Pattern Model for Different Morphing Attack Detection	1.046sec	1.069sec
Ulrich, Dhanesh, Martaand Christoph (2021)	A New Approach to the Recognition of Morphed Face Images	0.831sec	0.961sec
Raghavendra and Guoqianq (2022)	Present Multimodality for Dependable Face Morphing Attack Detection Based on Single Image	0.692sec	0.711sec
Iman and Khudiar (2023)	Proposed Generating and Detecting Face Morphing Using Texture Technique	0.418sec	0.4753
Developed LRP Face Morphing Recognition Framework	Enhanced Face Morphing Detection Using LRP	0.0532sec	0.0582sec

The developed LRP face morphing recognition has been trained and compared to existing literature in terms of performance and the results show that it has negligible difference in training time when compared with existing work.

4.1 Result of LRP Recognition Accuracy for Face Morphing Recognition

Table 4: Shows the Result Obtained from the Recognition System

Dataset	No Image	FAR	FRR	Accuracy
FERET	100	1.2%	1.1%	98%
FRGCv2	100	1.4%	1.3%	96%

Comparing the acquired results with the traditional feature extraction techniques, the employment of Residue Number System (RNS) and Local Binary Pattern (LBP) has shown the best performance. The obtained results demonstrate the applicability of the proposed scheme for automated morphed face detection.

5. Conclusion

This work used an Enhanced Local Binary Pattern algorithm for feature extraction to construct a face morphing recognition system. In this study, we explored the application of Local Binary Pattern (LBP) combined with the Residue Number System (RNS) for the detection of face morphing attacks. The integration of LBP, a powerful texture descriptor, with RNS, a method known for its robustness in error detection, has proven to be an effective approach in enhancing the time complexity and accuracy of face morphing recognition systems.

Our results demonstrate that this hybrid method offers significant improvements in distinguishing between genuine and morphed face images, addressing the limitations faced by traditional face recognition systems. By leveraging the strengths of both LBP and RNS, the proposed model not only improves detection accuracy but also ensures computational efficiency, making it a viable solution for real-world applications, such as security and identity verification.

The contribution of this work includes the issues of time taken, and recognition accuracy, which are the most obliging elements on the usefulness of the face morphing recognition system. The specific contributions of this research can be summarized as follows: This work implemented a Local Binary Pattern (LBP) scheme with an RNS-based technique to solve the problem of high dimensional features among the classes utilizing moduli-set $\{2n+1-1, 2n, 2n-1\}$. Results demonstrate that this scheme outperforms the existing system as far as the time taken is concerned. This work focused on minimizing error accuracy and providing high speed in face morphing recognition. However, several future research efforts could focus on the following areas for further improvement:

- (i) The presented enhanced LBP for the face morphing attack recognition scheme could be fused with other (differential) approaches to further improve the detection performance.

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