2D-3D Facial Image Analysis for Identification of Facial Features Using Machine Learning Algorithms with Hyper-parameter Optimization for Forensics Applications

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Abstract: The Face Recognition System is a remarkable process that humans naturally use, as a precursor to communicating nonverbal cues in their normal daily lives. Outside of this regime, face recognition systems are increasingly being used for recognizing faces in commercial and law enforcement applications. Currently, it is one of the most sought-after detection methods used in forensics for criminal identification purposes. Owing to similarities in the appearance of certain faces, face recognition systems today face substantial challenges in reliably identifying them in settings that require high detection rates. In addition, among criminal suspects found to have similar faces, this problem poses a great challenge in implementing forensic illegal and fraudulent activity detection. This study addresses the development of a detection pipeline that is data-driven, and fast, and incorporates structural information to overcome some of these issues. The novelty of this study lies in reconstructing a three-dimensional face mesh from two-dimensional images, of located 468 landmarks employing the media pipe framework. This two-dimensional to three-dimensional annotation provides a higher quality of three-dimensional reconstructed face models without the need for any additional three-dimensional morphable models. The proposed approach works better for detecting multiple faces in real-time and even in challenging uncontrolled conditions such as large pose variations, expression variations, and occlusion variations. The dataset consists of facial images collected from the web which provides the correct matching decisions in an unconstrained environment that is then used in forensic sciences to be presented as statistical evidence. Quantitative similarity measures are used as inputs for various classifiers to identify criminals in forensic investigations. The proposed methods were validated and tested to achieve comparable recognition performance and hint at the potential of further research for scale-up implementation.

I. INTRODUCTION

BIOMETRIC imprints are based on the understanding that each person is unique. The face is the most important factor in defining physical attractiveness. Humans can recognize each face's unique imprint based on its distinguishing traits. Face recognition examines the capability of human vision to measure faces for identification. As a result, there has been a lot of focus on designing algorithms that mimic the human vision process for face recognition. When other biometric modalities are unavailable, facial recognition, a type of biometric identification, is employed. Face capture, which is both natural and non-intrusive, has been shown to be one of the most effective biometrics for face recognition.With no definitive results, computer vision has attempted to mimic the capabilities of the human eye. However, face recognition appears to be a valuable and practical technology forensic examiners employ in criminal investigations [1] [2]. Face recognition is a popular scientific approach with a wide range of applications; however, it is prone to several problems. The challenges identified are automated face detection, recognition of face images such as identical twins and look-alikes, facial aging, occlusion, expression, and pose variation effects, illumination conditions, low resolution, quantitative and qualitative methods for setting parameters and estimating characteristics of the face, seeking solutions through digital anthropometry and other challenges [3]–[11]. Despite increased law enforcement, criminal offenses appear to be perpetrated at a high rate by people with similar faces, particularly identical twins [12]–[16]. According to a recent study, the face recognition system does not work as well in the case of identical twins as in the case of other people. Consequently, erroneous identification must be avoided to prevent the accidental conviction of an innocent individual. The identification of similar or similar-looking faces is difficult; therefore, there is significant motivation to pursue their recognition. The current facial recognition system failed to distinguish identical twins. In addition, deep neural networks face the same challenge of distinguishing between similar faces, such as identical twins, and look-alikes. Over the years, many approaches have been proposed using several recently developed and well-performing algorithms and databases, considering both favorable and unfavorable situations; however, these have been unsuccessful. Consequently, the primary goal of the proposed research is to accurately determine criminal identification in forensics-related fraud and crime. Although in the past, pursued progress has been made focusing on 2D face images, it still has drawbacks with regard to limitations in performance due to factors such as variation in head pose, expression, occlusion, illumination, etc. To overcome these limitations, researchers have focused on 3D face recognition technology which has the advantage of obtaining more geometric information about the face such as face margin curves, curvature characteristics, and geodesic distances, which could substantially improve accuracy. The main drawback of 3D model-based approaches is their inability to store large data files, which is computationally costly and not applicable to real-life face recognition systems [17]– [21]. The research community has provided a third solution that suggests a combination of 2D and 3D modalities [22]– [25]. This approach appears to be a reasonable solution that can overcome the limitations of improving each system. Similarity measures of 3D facial surface have become hot topics, that have important applications in face recognition, 3D facial reconstruction, facial surgery, 3D animation, biometrics metrics, forensics, and other fields. The similarity between two objects is often different when judged by different people, depending on the perception and experiences of each person. Therefore, similarity measurement is difficult. In particular, human face similarity is more difficult to measure because human faces are globally similar in terms of their main physi- cal features (eyes, mouth, nose, etc.) Remarkable approaches with the best algorithms and databases have been presented over the years, considering the favorable and unfavorable situations to study face recognition, and have been found unsuccessful in matching up to expectations. With the in- creased birth rate of twins, which is the cause of fraud and a growing crime rate, there is an urgent need to integrate the existing automated face recognition system with the forensic face recognition method, which has the immense liability to follow legal procedures. The main purpose of this study is to propose a novel framework for the recognition of faces employing 2D facial images to approximate 3D face mesh using 468 landmarks for the images collected from the web that can provide the correct matching decision in an unconstrained environment. This paper proposes a new data set for checking facial image com- parison. Face detection, pre-processing, landmark detection, feature extraction, identification, and authentication were per- formed as part of this study. Face landmark extraction must be quick and accurate to meet the demands of various capabil- ities, such as real-time processing or mobile device rendering [26]–[29]. Precise recognition of landmarks is performed using Mediapipe [30]–[34] which is mainly used in real-time applications such as emotion detection, Parkinson's disease detection, driver drowsiness detection, and early-stage autism screening [35]–[40]. It estimates 468 landmarks in real-time to improve the accuracy of the face recognition system (FRS) compared to other existing approaches, such as Multi-Task Cascaded Convolutional Networks (MTCNN) [41] [42] and Digital Library (DLIB) [43] [44]. Thereafter, Euclidean and Geodesic distances were measured from the selected land- mark points to extract the features. The quantitative similarity measures are then given as inputs to various classifiers such as Extreme gradient boosting (XGBoost), Adaptive Boost- ing (AdaBoost) classifiers, Random Forest (RF) classifiers, Bernoulli Naive Bayes (NB), Decision Tree (DT), Logistic Regression (LR), Light Gradient Boosting Model(LGBM), Extra Tree Classifier(ETC), Support Vector Machine (SVM), and Nearest Centroid (NC) classifiers to identify criminals in the forensic investigation by presenting them as statistical evidence. This study focuses on exploring the forensic aspects and applications of a biometric face recognition system.

II LITERATURE SURVEY

A. *LITERATURE REVIEW RELATED TO ANTHROPOMETRIC FEATURE-BASED FACIAL IMAGE ANALYSIS IN 2D AND 3D FOR FACE RECOGNITION*

Sudhakar and Nithyanandam [8] focused on a fusion-centered method for identifying identical twins. The features extracted using Histogram Oriented of Gradients (HOG), PCA, Gabor distance between the facial components, and local binary pattern (LBP) were combined in this study. The twins were identified using fusion-generated scores in this method. The best feature was selected by using Particle Swarm Optimiza- tion and an SVM classifier was used to train and test the image. Better outcomes with high accuracy and less process- ing time were obtained using this approach compared with the prevailing methodologies. However, images with various expressions and poses were considered, and realistic images were not considered for evaluation. Kukharev et. al. [9] presented a review that included a brief history of anthropometry and its evolution into modern meth- ods and approaches using computer science for facial anthro- pometry, issues on morphometry, qualitative and quantitative methods for setting parameters and estimating characteristics of the face, distinctive cases in the recognition of face images such as identical twins and look-alikes, and various solutions through digital anthropometry. E. Moung et. al. [10] reviewed solutions using state-of-the- art techniques to address the challenges faced in face recogni- tion. The identified challenges are (i) automated detection of the face (ii) angle of face poses (iii) effects due to occlusion (iv) various facial expressions (v) face aging, (vi)different light conditions, (vii) low-resolution images, (viii) similarity in twins and faces that look alike, and (ix) other technical challenges. To authenticate identical twins in addition to the face recognition biometric system, other biometrics have been proposed. Bouchra et. al. [11] presented an FRS based on 3D, us- ing "Geodesic Distance" - GD measured using Riemannian geometry and "Random Forest"-RF. Subsequently, to solve the Eikonal equation, the algorithm named "Fast Marching

-FM" measures distances geodesically between a set pair of points of 3D faces, thus naming it GDFM+ RF. To analyze class separability, "Principal Component Analysis"-(PCA) was employed on the extracted features drawn from the geodesic facial curves. The extracted features are then applied to the "RF" classifier as the input feed. The authors suggested that to investigate the method's effectiveness, instead of "Fast Marching," it is best to use any other algorithm to compute the geodesic distances. Afaneh et. al. [45] used a two-level decision method to propose a system for recognizing identical twins. They ap- plied score-level, feature-level, and decision-level fusion; to improve accuracy, a CNN was employed in the recognition process. Feature extractors such as PCA, LBP, and HOG were used in this study for the standard FERET datasets and ND TWINS-2009-2010. The experiments proved that compared to unimodal systems, the multimodal biometric system improved recognition performance. For identical twin recognition, the Equal Error Rate obtained for the Controlled Illumination Condition was 2.2 (%), and that for the neutral expression was 2.7 (%). Mousavi et al. [46] suggested a Modified SIFT (M-SIFT) algorithm along with crowdsourcing to distinguish the similar faces of identical twins. The eyebrows, eyes, nose, mouth, and face curves are the five regions in which the face in each image is partitioned. Among the facial five regions, these approaches ascertained that the face curve was the most significant facial feature for discriminating between identical twins. A total of 650 images were obtained from 115 pairs of identical twins and 120 non-identical twins using this method. The experiential outcomes showed that 7.8%, 8.1%, and 10.1% had the lowest Equal Error Rate (EER) of identical twin recognition for the entire image, only frontal images and PAN motion images, respectively. However, landmark regions cannot be detected using the face region landmarks detection (FRLD) algorithm. Nafees and Uddin [47] presented a gray-level co-occurrence matrix that measured the texture of images to predict twins. To match the initial stage, the best criteria are identified using the histogram and RGB colors in this framework. The security vulnerabilities associated with twin- face identification and detection were prevented using the proposed method. Diverse twin datasets were used to test this methodology. When analogized with other methodologies for the prediction of twins better performance was attained by the presented method with good accuracy. This approach can also be applied under controlled circumstances that are adaptable to a wide range of facial variations. However, this method requires a long processing time. Jasbir Dhaliwal et. al. [48] used traditional feature-based approaches (angular and linear) handcrafted by researchers to calculate the measurements using landmarks. This approach has been used to study sex and ethnicity, thereby confirming its success. This approach verified for the first time that facial anthropometric measurements could be employed on 2D data sets developed through computer science. Thus, computer science researchers have been motivated to study facial an- thropometry. Rachid et. al. [49]presented two feature extraction meth- ods to achieve a 2D face recognition system using detected facial feature points, thereby computing between points to measure their distances using "Geodesic Distance" - GD and "Euclidean Distance"-ED, as in Riemannian geometry and Euclidean geometry, respectively. These measured distances were then used as inputs for various classification algorithms, and the results revealed that computing "GD" for extracting image features is more efficient than using "ED".

B. LITERATURE REVIEW RELATED TO FACE RECOGNITION USING MACHINE LEARNING ALGORITHMS

Xia Wang et. al. [50] proposed an approach that combined LBP and SVM to develop a system for 3D face recognition. The authors used the LBP algorithm and SVM classifiers for feature extraction and classification, respectively. The results prove that the algorithm requires less time, improves accuracy, is less complex, and is faster. The Transfer Learning (TL) method was utilized by Khalid et.al. [51]. Geometric and photometric characteristics were used. Two VGG16-trained networks are considered. The combination of geometrical and photometric features yielded 98 percent accuracy. Therefore, there is a need for more identical twin imaging data. Google Data includes four pairs of twins, each with 17 different positions; the photometric characteristics provide 96 percent accuracy. Existing modal- ities, such as palm print, face, voice, and others, can be used with other transfer learning methods. Ahmad et. al. [52] proposed a deep neural network to identify identical twins. Using triplet loss, they employed two alternative CNN models. The best accuracy attained was 87.20 percent, which shows that identical twin faces are a very difficult challenge for strong, deep networks. Khawla et. al. [53] [54] presented a deep learning-based fa- cial recognition attendance system. SqueezeNet, GoogleNet, and AlexNet were the three networks used. Similar and veiled faces are not recognized using this technology. To improve performance, more pre-trained CNN models can be used. Hamayun et. al. [55] considered “Classifier Ensemble” techniques and “Feature Fusion” to propose an adaptable face recognition system. To achieve enhanced classification results, they used a “Classifier Ensemble” technique, rather than a single classifier. The type and number of base classifiers, type of features, dimensionality of features collected in the feature space, and ensemble learning techniques, are the various factors that influence the performance of their classification system.

C. LITERATURE REVIEW RELATED TO FACE RECOGNITION IN FORENSICS

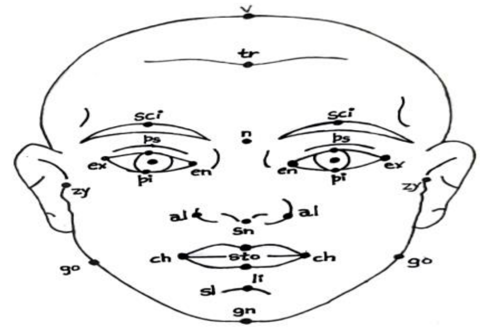
Asogwa et. al. [1] presented a novel system that differentiates two similar suspected faces of different identities using a bag of features by applying machine learning algorithms to recognize identical twins to support global crime investigation. This study has successfully provided a new pathway to support digital forensic investigation by, employing artificial intelligence (machine learning) to improve the existing face recognition systems. The accuracy and time taken in the recognition process of this system can be further improved using a “K-NN” classifier or a “Neural Network” instead of a “Support Vector Machine”. Forensic Image Analysis [56] is a new set of parameters that uses indices to derive image ratio-based facial features defined geometrically. This rule book probes one to inves- tigate the possibility of deriving multiple anthropometric measurements and their ratios to enhance face recognition accuracy. Tauseef Ali et. al. [57] reviewed forensic facial identifica- tion, a forensic expert method for manual facial comparison. The Bayesian framework is discussed and how it can be adapted to forensic face recognition is elaborated. Several issues related to court admissibility and reliability of the system are also discussed. Andrea et. al. [58] projected the use of a Bayesian proba- bilistic framework to discuss a method of presenting evidence evaluation in court. Institutions such as ENFSI encourage the use of a Bayesian framework to report evidence to the Court of Justice as a suitable way to standardize reasoning. Three different open-source automated systems such as “OpenFace”, “SeetaFace”, and “FaceNet” - all three based on “Convolu- tional Neural Networks” were used in this approach, after which the similarity or distance obtained is then converted to a likelihood ratio. The obtained LR was validated in a courtroom by a human expert. Khalid et. al. [59] used “Golden ratio” based- features and “Bayes Classifier” to present an approach for the classifi- cation of gender and recognition of humans based on their face sketch images. The approach includes computing two golden ratios namely width face ratios and height face ratios. To develop a criminal identification process, classification, and recognition are performed using golden ratios and Bayes classifiers.

III. BACKGROUND THEORY

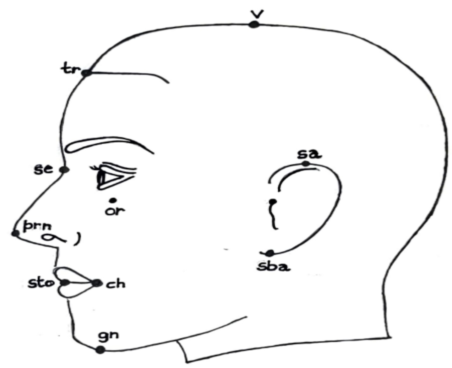
The standard view among face recognition researchers is that determining the resemblance between faces, particularly in cases of look-alikes in criminal investigations, is the most demanding and challenging. Biometric prints generated from the faces of look-alikes, particularly identical twins, have been found to be remarkably similar. Over the years, remark- able approaches using the best algorithms and databases have been presented to explore face recognition in both favorable and unfavorable situations, but have been found to fall short of expectations [3] [6] [9] [10] [12] [13]. With the increased birth rate of people with similar facial features, there is greater ur- gency and need to integrate existing automated face recogni- tion systems with forensic face identification methods, which have a high level of legal liability. This may reduce fraud and increase crime rates by considering the source features.

A. *DIGITAL FACIAL ANTHROPOMETRY*

Physical anthropology at the end of the 13th century was initiated as descriptive and comparative science also known as forensic science by the Italian merchant Marco Polo (1254–1324). In the 18th century, Alphonse Bertillon, a French police officer, and a bio-metrics researcher (1853–1914) developed a breakthrough system for crimi- nal identification based on the anthropological technique of anthropometry, on which the facial recognition system was built. Anthropometry is the scientific study of the measure- ment and proportions of the human body. Morphometry is a branch of mathematics that deals with the quantitative analysis of size and shape. It is a combination of geometry and biology that deals with the study of shapes in two or three dimensions, respectively. Qualitative and quantitative features were used to describe human faces. Anthropometric measurements involve the identification of certain points on a subject's face, called landmark points. Facial landmark extraction is the process of plotting face key landmarks rep- resenting important regions of the face such as the tip of the nose, center of the eye, etc. of an image. It allows for identifying the shape and orientation of the face, as well as extracting facial features [48]. Figure 1 shows the digital record of anthropometric ref- erence points and the definitions of various distinguishable landmarks of the face are provided in Table 1.



(a) Anthropometrical reference Points



(b) Anthropometrical reference points with pose variation.

FIGURE 1. Anthropometrical reference points

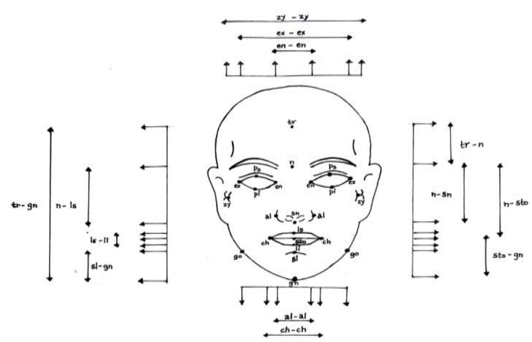


FIGURE 2. Anthropometrical landmark-based measurements

Figure 2 shows the process of measuring various distances, such as the Euclidean Distance (ED) and Geodesic Distance (GD) such as the distance between Alare and Alare (nose width), Cheilion to Cheilion (mouth width), exocanthian to chelion (upper cheek height), nasion to sub nasale (nose height), sub nasale to chelion (upper lip length), sub nasale to gnathion(lower facial height), and stomion to labiale infirious (vermilion height of the lower lip) using the extracted pair of landmark points. By using these measured distances different facial ratios such as Inter canthal width to Bizygomatic breadth, Vermilion height of the upper lip to Vermilion height of the lower lip, can be obtained.

In the proposed approach, after detecting the face position in an image, the next step is to locate 468 landmarks using a media pipe [30]–[33]. Mediapipe is an open-source frame- work for "building world-class machine learning solutions" using Google which is fast and highly accurate [30] [34]–[40]. 2D facial images are used to detect 3D face meshes (which include 468 facial landmarks with 3D space coordinates) by employing the media pipe framework which works well for varying lighting conditions, occluded faces, and faces of various sizes and orientations in real-time. More information is derived from the facial mesh topology than is needed, which also makes it possible to select only the necessary information.

FIGURE 3. Four Sixty-Eight facial landmarks for a frontal image and for images with pose variations in 3D space

A total of 468 landmarks were acquired for the facial images with different poses as important features which are shown in Figure 3. Figure 4 shows the result of generating 468 landmarks, overlaying 468 landmarks on facial images of the self-created dataset, and generating face mesh with different poses from the extracted 468 face landmarks.

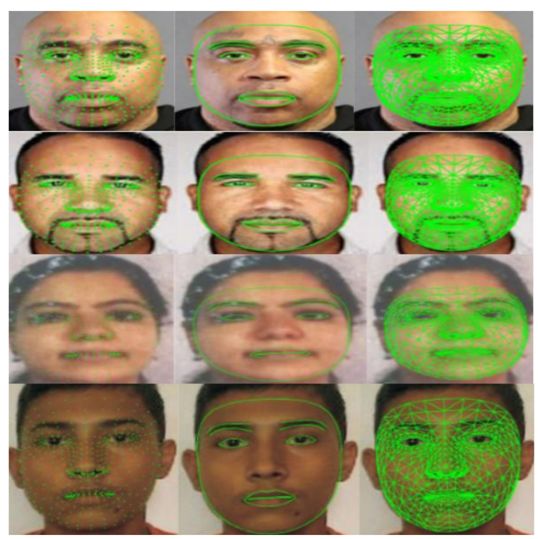


FIGURE 4. Overlaying 468 landmarks on facial images [61], [63], [65] of the self-created dataset and generating face mesh with different poses from the extracted 468 face landmarks

IV METHODOLOGY

A new framework for the recognition of different face cate- gories such as the same images, different images, and look- alikes. using facial images is presented to make a perfect deci-sion in face identification using machine learning algorithms. Two-dimensional (2D) facial images were selected from the dataset. Every chosen image underwent pre-processing for the detection and normalization of the face. The proposed system was used to accurately localize 468 landmarks on 2D facial images, and these landmarks were overlaid on a 3D facial image using which a 3D face mesh was generated. Feature extraction is then performed by measuring distances between pairs of anthropometric points using "Euclidean Dis- tance", and "Geodesic Distance". Their ratios are based on curves, and the curvature characteristics are used to generate a fusion of features. The results are given as inputs to multiple classifiers such as XGBoost, AdaBoost, RF, NB, DT, LR, LGBM, ETC, SVM, and NC classifiers. To select the top- performing machine learning models, the lazy-Predict pack- age was used, which compares the effectiveness of various machine learning models for a dataset. The performance of this framework was evaluated for accuracy, error rate, recall, precision, and F-measure.

Pre-processing, face detection, landmark detection, 3D mesh generation, feature extraction utilizing Euclidean and geodesic distances, classification, and performance evalua-tion are the various phases of face comparison and authen- tication, as shown in Figure 5.

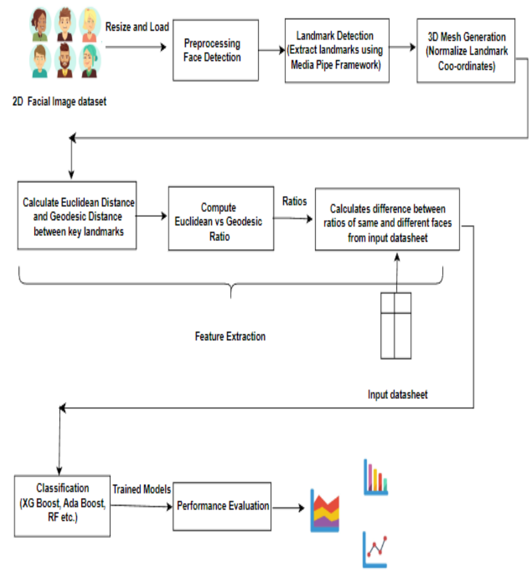


FIGURE 5. Schematic illustration of the process of the proposed approach

Pre-processing: 2D face data were acquired to pro- vide "clean" faces for detection and normalization. In the proposed approach, a face image is initially se- lected, and pre-processing operations such as cropping and scaling are performed to generate a facial image dataset.

Face Detection: This is the process of detecting a hu- man face in an image using a set of data. Detecting the face in photographs is difficult because the identified findings are based on several elements, such as the environment, illumination, movement, orientation, and facial emotions. In the proposed method, face detection is performed using Mediapipes' face detection model, which detects the face in real-time using an image or video as the input.

Landmark Detection: This enables the accurate and reliable identification of facial landmarks. A few pre- cise images were mapped onto individual facial pho- tographs to obtain the required measurements. The pro- posed approach was used to locate and extract features automatically. In the present work, 468 landmarks were extracted instead of 68 to improve the accuracy using the Mediapipe library [35]–[40]. The media pipe frame- work was used to detect multiple faces and 468 face landmarks in a 3D space. This face geometry solution estimates 468 face landmarks in real-time, even on mobile devices.

3D Face Mesh Generation: A total of 468 landmarks extracted from the 2D facial image were overlaid on the 3D image to generate a face mesh, which is a 3D model of the face. The face mesh detection API creates a face mesh with 468 3D points, edges, and triangle information for each detected face.

Feature Extraction: This process obtains digital de- tails, figures, or particulars from raw data from the most distinctive region extracted. Only discriminatory infor- mation was contained in the retrieved features, which were used to identify individuals. The present study used both Euclidean and geodesic distances and their ratios as features. Feature extraction is proposed for the entire face by calculating the Euclidean and geodesic distances between facial geometric points based on the Anthropometric Model. The geodesic distance is based on curve and curvature characteristics, and the Euclidean distances between facial fiducial points and their ratios were computed. Table 2 illustrates the sam- ple Linear and Geodesic Distances used in the proposed approach for facial analysis in four facial regions: the forehead/eyes, nose, lips, and chin. This is broadly used to illustrate faces that are measured from 468 land- marks, namely "Anthropometric Reference Points."

Classification: This is the process of arranging data into labeled classes using a classifier algorithm. The classification results were based on two image classes: SAME and DIFFERENT. In the proposed approach, the extracted ratio-based features are given as inputs to multiple classifiers such as XGBoost, AdaBoost, RF, NB, DT, LR, LGBM, ETC, SVM, and NC classifiers. These classifiers are used to learn discriminatory fea- tures to develop a perfect system for face recognition and verification of criminals that support and improve forensic investigation.

Performance Evaluation: Performance results of the proposed framework are evaluated for Accuracy, Error rate, Recall, Precision, and F-measure.

DATA COLLECTION AND DESCRIPTION

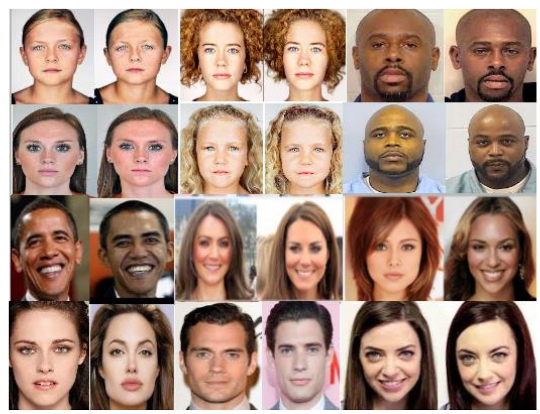


FIGURE 6. Sample facial images of the dataset

A data set comprising 600 images of faces collected from different sources (public) which include individual male and female faces, different images of the same person, lookalikes, and other issues are used in the proposed study as shown in Figure 6. The format used for representing images in the dataset follows JPEG and PNG. From the dataset, 70% of the images were used for training, and 30% of the images were used for testing. The preliminary step after obtaining the dataset is eliminating noise using suitable pre-processing techniques (removing noise from the images eg. Gaussian Blur, resetting the image resolution to extract necessary features, Morphological Transforms may be used to enhance the foreground and background of the image, aligning and rotation of images, suitable scaling).

FACIAL IMAGE ANALYSIS

A human face image was selected on which the anthropometric landmarks were plotted. Subsequently, the facial image is analyzed for feature extraction by measuring the distances between any two landmarks using Euclidean and geodesic distances along the face curve. Sample landmarks are shown in Figures 7 and 8 because manual annotation of 468 points is difficult.

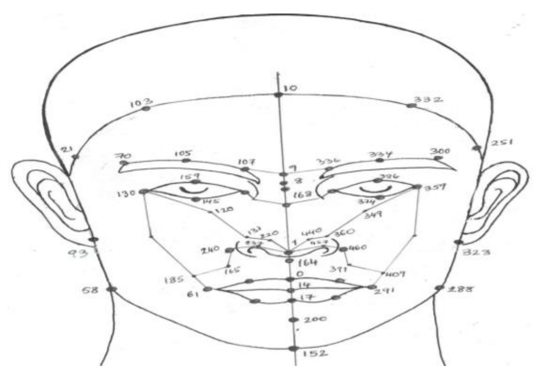


FIGURE 7. The facial image analysis using sample anthropometric landmarks

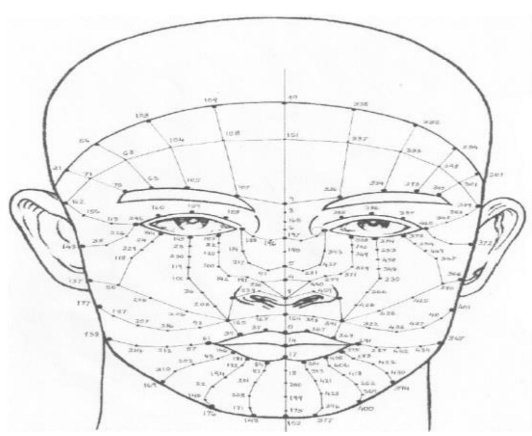


FIGURE 8. Full face analysis using most significant anthropometric landmarks

Figures7 and 8, showthe analysis of facial images using the anthropometric landmarks of various facial regions. Facial image analysis performed in 3D space is represented here by considering 2D facial images

V RESULTS AND DISCUSSION

To identify criminals in facial images, the performance of several supervised ML classifiers was measured using test data based on a confusion matrix using different classification algorithms for the dataset. Different evaluation metrics were used to justify the comparative analysis. Experiments showed that XGBoostwas the best classifier. AdaBoost performed the best, whereas RF and LR performed better than the other algorithms in terms of sensitivity, specificity, and error rate. The final results of the model classification were compared to de-- termine which approach had the best accuracy and enhanced the performance of the model. The number of accurate and incorrect predictions is calculated using a confusion matrix, which is supplied by the sklearn metrics module and is used to obtain precision, recall, accuracy, and other metrics. Table 4 presents the confusion matrix with true positives (TP), true negatives (TN), false positives (FP), and false negatives (FN). For TP predictions in a binary classification issue, the model accurately predicts the positive class (both the prediction and the actual are positive). The model successfully predicts the negative class for TN (both predicted and actual are negative). In the case of FP predictions (TYPE I error), the model provides an incorrect prediction for the negative class (predicted-positive, actual-negative). The model mispredicts the positive class for FN Predictions (TYPE II error) (predicted, negative, and actual-positive). Based on the confusion matrix, the following measures are commonly used to analyze the performance of classifiers based on supervised machine learning algorithms.

VI CONCLUSION

An FRS using anthropometric and morphometric measure- ments to extract discriminated features from different cat- egories of facial images was proposed and implemented. The proposed system accomplishes an efficient approach to accurately recognize criminals with statistical evidence that supports and improves forensic investigations by a multi- parametric anthropometry model. The results obtained prove that the research work conducted stands with their contempo- raries. Future work will investigate more robust approaches to improve the accuracy of the present study by considering a more extensive database of facial images and selecting the best classifier by combining more than one image. Identifying identical twins is an open challenge; hence, constructing a multi-modal FRS system, possibly using various modalities, is required.

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