MAHYA: Facial Recognition-Based Pilgrim Identification System for Enhanced Health Monitoring and Assistance

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***Abstract*—During the Hajj season, Saudi Arabia experiences the arrival of millions of pilgrims from diverse linguistic and geographical backgrounds. This influx poses significant challenges for emergency medical care services. The primary objective of this study is to explore the technological shortcomings and difficulties encountered by healthcare teams during such large-scale gatherings and to propose improvements for more effective emergency medical response systems. This study introduces MAHYA, a mobile health technology application designed to enhance emergency medical responses. MAHYA integrates advanced facial recognition technology, utilizing Inception ResNet V1 and Siamese network algorithms, to quickly and accurately identify individuals and retrieve their medical histories. This quick access to vital medical information is crucial for timely and efficient emergency medical care. The app incorporates a few-shot learning approach to bolster its facial recognition capabilities, which is vital to manage the large number of pilgrims. Further technical aspects of MAHYA include its use of Flask for back-end operations, Python for data processing, and NGROK to ensure secure external connectivity. These features collectively empower the application to offer a highly effective, secure, and adaptive facial recognition service, tailored for the dynamic and densely populated environment of the Hajj. The findings of the deployment of this application indicate a substantial improvement in the operational efficiency of healthcare professionals on the ground, leading to faster response times and improved overall quality of emergency medical services.**

Keywords*—*Facial recognition; emergency medical care; ResNet inception; Siamese network; mobile health technology

I. Introduction

During the Hajj season, the convergence of millions of pilgrims from diverse linguistic and geographical backgrounds poses significant challenges for emergency medical services in Saudi Arabia. The 2023 season alone witnessed more than 1.66 million pilgrims, underscoring the pressing need for efficient healthcare delivery among such large gatherings [1]. Traditionally, emergency medical personnel face substantial hurdles, including severe language barriers and the absence of readily accessible medical histories, which critically hamper the speed and precision of medical responses [2].

The MAHYA mobile application emerges as a pioneering solution designed to harness the power of digital technology to address these challenging aspects. Using advanced facial recognition algorithms, specifically Inception ResNet V1 [3] for feature extraction and the Siamese network for identity verification [4], MAHYA facilitates the immediate retrieval of medical records [5]. This process not only bypasses linguistic barriers, but also significantly reduces the time required for paramedics to access vital health information.

Developed using the robust Flutter framework and interfacing with a Python-based backend via a Flask-based API [6], MAHYA ensures seamless operation and integration across different platforms. The design of the app prioritizes user-friendly interfaces that allow paramedics to efficiently navigate essential features, including real-time data updates [7] and secure access to pilgrim medical records, allowing more effective on-site medical decisions [8].

The novel contributions of the MAHYA application are multifaceted. First, it introduces an innovative use of facial recognition technology tailored to the unique context of the Hajj, addressing both access challenges to identification and medical history in a comprehensive way. Furthermore, the application ensures data security and privacy by restricting access to sensitive medical information to authorized personnel only, a pivotal aspect given the sensitivity of health data. Furthermore, MAHYA's architecture supports quick scalability and adaptability to accommodate the vast number of pilgrims and the dynamic nature of the Hajj environment.

The implementation of MAHYA marks a significant advance in emergency medical services during large-scale religious gatherings [9]. Its success could serve as a model for similar applications in other contexts where quick medical response is crucial and faces similar challenges. Looking ahead, the project team envisions further enhancements, such as integration with real-time location tracking and predictive analytics to anticipate and manage potential medical incidents more proactively [10].

In this study, the key obstacles that emergency medical teams face during Hajj, such as significant language barriers and the lack of readily available medical histories, are critically examined. These challenges substantially impair the effectiveness and precision of medical interventions, complicating communication and the acquisition of vital health information from pilgrims.

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In addressing these obstacles, the research probes several questions. How can technological solutions mitigate the linguistic and informational barriers that hinder effective emergency medical care during Hajj? In addition, what impact does facial recognition technology have on improving accessibility to medical histories?

Focusing on solutions, the main goals of this research are to identify and address technological shortcomings within current emergency medical services provided during Hajj. A pivotal part of this initiative is the development and deployment of the MAHYA mobile application, which incorporates cutting-edge facial recognition technologies such as Inception ResNet V1 and Siamese networks. This integration aims to facilitate the quick and precise identification of individuals and enable immediate access to their medical records.

Research has significant potential to transform emergency medical services during Hajj. By streamlining response times and improving the accuracy of medical care, the MAHYA application represents a substantial advancement in real-time medical response capabilities. Such improvements are crucial to effectively managing the health crises that frequently occur during large-scale religious gatherings, underscoring the importance of this research in enhancing public health safety and response strategies.

The subsequent sections of this paper are designed to meticulously outline and analyze the components and implications of the MAHYA application. Following this introduction, the 'Literature Review' section delves into previous studies and technologies that intersect with our approach, providing context and justifying the need for an advanced solution like MAHYA. Then, in the 'Methodology' section, we detail the technological frameworks and algorithms employed, specifically elaborating on the implementation of Inception ResNet V1 and Siamese networks within our system's architecture. The Results and Discussion sections evaluate the performance of MAHYA and discuss the operational advancements our application presents for emergency medical services during Hajj. Finally, the 'Conclusion' section summarizes the findings and potential future developments of MAHYA, reinforcing the contribution of the application to the field of emergency medical services in large-scale events. Through this structured approach, the article aims to provide a thorough understanding of the development and strategic importance of MAHYA.

II. Problem Overview

During the Hajj pilgrimage, managing the health and safety of more than one million attendees from diverse cultural and linguistic backgrounds presents a formidable challenge. Language barriers and the inaccessibility of medical histories significantly impede the efficiency of medical responses. In 2022, these complications were highlighted, as 22,644 pilgrims required medical attention, 18,277 of which were emergency cases. The lack of readily available medical histories complicates treatment options, leading to possible medical errors and adverse outcomes.

A study involving 66 volunteer paramedics identified severe difficulties in treating non-Arabic and non-English speaking pilgrims; see Fig. 1. The main concerns included the absence of a centralized medical database, language-driven communication barriers, and logistical issues in accessing timely medical data. These challenges underscore the urgent need for a systematic approach to improve diagnostic capabilities and treatment accuracy during large-scale religious gatherings [5].

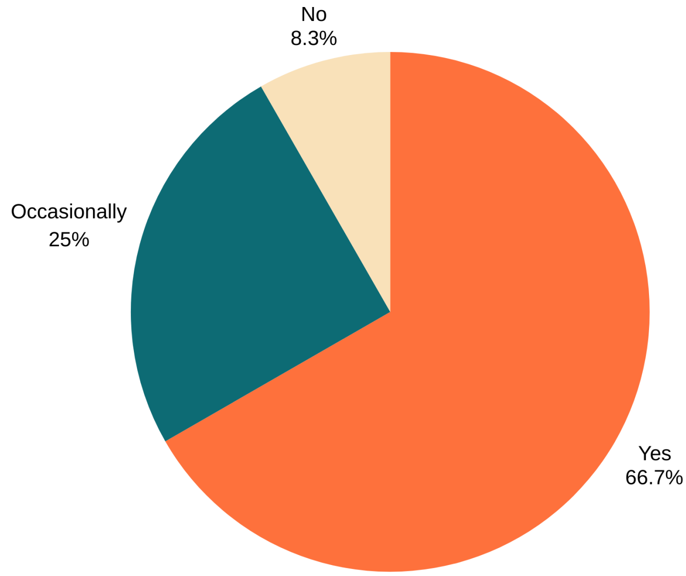

Fig. 1. Responses to the question "Have you faced challenges in knowing the medical history of pilgrims in cases of fainting and fatigue?".

III. Literature Review and Related Work

The section on related work provides a comprehensive review of existing technologies and methodologies relevant to the improvement of emergency medical services, particularly in culturally and linguistically diverse settings such as the Hajj pilgrimage. This research aims to identify the technological gaps and challenges faced by medical teams during such events [11], offering a pathway toward the development of more efficient emergency medical response systems.

A. Facial Recognition in Healthcare Access

A notable study explored the potential tasks performed by a Face Recognition System to access electronic medical record information in outpatient scenarios. The system used integrated hardware and software components to enable facial recognition to accelerate medical service processes [12]. More studies highlighted improvements in user acceptance and the efficiency of medical record handling, pointing to the utility of face recognition technologies in healthcare settings. However, issues such as scalability and the requirement for additional hardware were identified as limitations, suggesting areas for further development in emergency scenarios [13].

B. Simplification and Accessibility Improvements

Another piece of research introduced a facial recognition and verification system aimed at simplifying the process of obtaining patient health records [14]. This system used minimal hardware, using a Raspberry Pi and a webcam to perform facial recognition and detection tasks [15], [16]. This approach has demonstrated the potential to reduce the logistical burdens of hardware to access patient information, particularly in fast-paced and resource-limited settings [8].

C. Mobile Integration for Resource-Limited Settings

Further expanding this line of inquiry, the deployment of a mobile facial recognition system was examined to assess its effectiveness in improving patient identification in medical emergencies in developing economies [17]. Using mobile technology, this system offered a promising solution to provide immediate access to medical records during emergencies [15]. This initiative highlighted the importance of mobile solutions in emergency healthcare, highlighting challenges such as ensuring participation and maintaining data precision [7].

D. Data Security and Privacy Concerns

In terms of addressing data privacy and security issues, subsequent research initiatives have focused on ensuring secure and ethical management of patient data when utilizing biometric [18] and face recognition technologies [19]. This research underscored the necessity of incorporating stringent data protection measures to prevent unauthorized access and ensure patient confidentiality, a cornerstone of technology acceptance in healthcare settings [20].

Each of these studies collectively informs the current research project, illustrating how face recognition technology can be used effectively to serve highly diverse and transient populations during mass gatherings such as the Hajj [21]. In addition, these studies emphasize ongoing challenges, such as the need for hardware, integration complexities, and the critical dependence on robust data infrastructures. These challenges set the stage for the objective of this study: devise a more adaptable, integrated, and mobile-based solution that mitigates these barriers while improving the speed and precision of emergency medical responses [22].

IV. Proposed Solution

To address the significant challenges faced by paramedics during the Hajj season, a targeted solution has been proposed that focuses on the efficient management of healthcare services. The proposed solution involves the development of MAHYA, a specialized mobile application designed to improve the accessibility of medical histories for paramedics during emergencies. This application employs advanced facial recognition technology that uses Inception ResNet and Siamese algorithms, ensuring quick and accurate identification of pilgrims and immediate access to their medical records.

The application, built on the Flutter framework, integrates with a Python-based Flask API, facilitating the dynamic retrieval and updating of health records from a centralized database maintained by the Saudi Ministries of Health and Hajj and Umrah. By using this technology, paramedics are empowered to provide timely and precise medical interventions, significantly improving the quality of care provided to pilgrims. This is particularly crucial given the complex demographic composition of the Hajj participants, which includes a large number of non-Arabic speaking pilgrims.

Furthermore, the system features a robust security protocol to ensure that only authorized personnel have access to sensitive medical data. This measure not only protects the privacy of the patient, but also increases trust in the healthcare process during the pilgrimage. Thus, MAHYA is envisaged not only as a tool for emergency medical response but also as a platform to improve overall healthcare service delivery during the Hajj, addressing both current and potential future challenges in medical management during large-scale religious gatherings.

A. MAHYA Process Flow

The process flow within the MAHYA application is strategically designed to ensure seamless operation during the Hajj pilgrimage, addressing the significant challenges of language barriers and limited access to medical history. The streamlined sequence begins with paramedics logging into the application using their credentials tied to the Saudi Ministry of Health database. This secure log-in process ensures that only authorized personnel can access sensitive medical information.

Upon encountering an injured pilgrim, the paramedics can utilize the MAHYA's facial recognition capabilities to identify the individual either through an uploaded photo or directly using the app's interface. This photo is then compared against the preexisting database maintained by the Saudi Ministry of Hajj and Umrah. Once the pilgrim's identity is confirmed, the app provides access to their comprehensive medical records stored in the database.

The paramedic is then able to review, update, and annotate the pilgrim's medical record directly within the app, ensuring that all actions taken and observations noted are up-to-date. This updated information becomes part of the pilgrim's permanent medical record, securely stored within the Ministry's database. It is critical that these updates are synchronized across the system to maintain the accuracy of medical records.

V. Methodology

This section delineates the methodology adopted for the development and operationalization of MAHYA. Starting with data acquisition essential for its functionality, the authors subsequently discuss the technological frameworks and algorithms implemented for system execution, followed by a detailed description of data output.

A. Data Acquisition for MAHYA Operation

Data integrity and comprehensiveness are crucial for the effective operation of MAHYA. This subsection details the types of data collected and the processes involved in their acquisition.

Critical to the project, pilgrim data comprises personal identifiers and medical histories, which are crucial for providing personalized medical interventions during the Hajj. These data are collected through the Saudi Ministry of Hajj and Umrah platform, which collects detailed health information during the issuance of Hajj permits [23]. Stakeholder surveys with healthcare professionals and first aid providers helped identify the essential data types necessary for effective healthcare delivery. Such data include documented health conditions, ongoing treatments, and prescription details, improving the ability of medical personnel to provide timely and appropriate medical care [24].

To ensure data security and authorized access, the Saudi Ministry of Health maintains a verified list of paramedics authorized to serve during Hajj. This list is vital to protect pilgrim privacy and restrict access to sensitive medical and personal data, safeguarding it against unauthorized access.

B. Development Framework and Back-End Services

MAHYA is built using the Flutter framework, noted for its ability to produce native compiled applications for mobile, web, and desktop from a single code base. Flutter, which uses the Dart programming language, is highly favored for its fast rendering and customization widget sets, making it ideal for creating highly responsive user interfaces. This strategic choice facilitates rapid development cycles and eases the maintenance and scalability of the application as it evolves to meet changing requirements.

On the back-end, MAHYA employs Firebase, a robust Back-end-as-a-Service (BaaS) platform offered by Google. Firebase provides a suite of cloud-based tools that are crucial for developing complex applications such as MAHYA [25]. Its real-time database service allows immediate synchronization of data across all client apps, which is vital to ensure that medical information is updated instantaneously across platforms. This feature is particularly essential during the Hajj, when timely access to current medical records can substantially impact the effectiveness of emergency responses.

Firebase also offers powerful user authentication, which is used to secure access to the MAHYA system, ensuring that only authorized paramedics and medical personnel can access sensitive data. Its scalable infrastructure ensures that the system remains responsive and operational under the heavy loads typically experienced during the Hajj seasons, when thousands of simultaneous queries and data entries might be made.

Additionally, Firebase's support for cloud functions further enhances the capabilities of MAHYA by allowing the development team to implement complex server-side logic without managing server configurations. This server-less computing enables automatic scaling with demand and integrates seamlessly with other Firebase services, facilitating efficient, real-time data processing.

In general, the combination of Flutter for front-end development and Firebase for back-end services provides a robust, scalable, and efficient framework that supports the dynamic and demanding environment of the Hajj, ensuring that MAHYA can provide high-quality and reliable medical support services [26].

C. Facial Recognition Algorithms

The facial recognition capabilities of MAHYA are anchored in cutting-edge machine learning technologies, specifically designed to operate with limited training data.

1) Implementation of few-shot learning: The implementation of few-shot learning in MAHYA is a pivotal technological advancement that enhances the facial recognition system's capability to accurately identify individuals with minimal training data. This method is particularly relevant given the diverse and transient population of pilgrims during the Hajj, where acquiring extensive labeled data sets is impractical.

Few-shot learning operates under the premise of "learning to learn," focusing on rapid adaptation to new tasks with only a few training examples for each class. This approach is critical for MAHYA, as it must quickly adapt to new facial data each year. The system employs a sophisticated model architecture designed to generalize small data samples effectively [27].

The core of few-shot learning in MAHYA involves the use of a Siamese neural network paired with a triplet loss function. The Siamese network architecture consists of two identical sub-nets, which accept different inputs but are joined at their outputs [28]. This setup measures the distance between the embeddings produced for each input, facilitating the comparison of facial features in a dimensional space where similar features cluster together and dissimilar ones are apart.

The triplet loss function further refines the learning process by comparing a baseline (anchor) input, a positive input (the same class as the anchor), and a negative input (different class from the anchor). The goal is to train the model so that the distance between the anchor and the positive example is minimized, and the distance between the anchor and the negative example is maximized [29]. This approach enhances the model's discriminative power, improving its ability to recognize new faces with higher precision.

Training is carried out using carefully curated subsets of the Labeled Faces in the Wild (LFW) dataset [30] and Selfies & ID Images Dataset [31], which consists of various facial images categorized into numerous classes. This data set provides a varied range of human faces, which helps in crafting a robust model capable of generalizing well to new, unseen faces. The encoder model uses the Inception ResNet V1 architecture for optimal feature extraction, ensuring detailed and nuanced detection of facial features [32].

Finally, for the detection phase, multitask cascaded convolutional networks (MTCNN) are used. MTCNN excels at detecting faces within images quickly and accurately, which is crucial for the real-time requirements of MAHYA during Hajj operations [33], [34], [35]. Through the combination of these advanced methods, the few-shot learning system in MAHYA becomes a powerful tool for delivering reliable and rapid facial recognition capabilities, essential for effective medical management during pilgrimage [36], [37].

2) Multi-task Cascaded Convolutional Networks (MTCNN): Face detection serves as a foundational component for numerous facial analysis applications, including face recognition [38] and expression analysis [39]. The challenges associated with dynamic face recognition are amplified by variations in visual representation, postural changes, and lighting conditions that influence facial feature perception. Effective face detection technology must proficiently identify and localize faces across diverse images, notwithstanding variations in scale, orientation, and pigmentation. Research in face detection has continuously explored areas like expression recognition, facial tracking, and pose estimation [40]. The inherent non-rigid structure of human faces, coupled with factors such as varying image quality, occlusions, and diverse lighting scenarios, necessitates robust detection methods capable of performing under less-than-ideal conditions.

The MTCNN algorithm addresses these challenges through a structured, three-stage process as depicted in Fig. 2:

- Proposal Network (P-Net): In this first stage, the input image is subjected to a series of convolutional layers to flag potential face regions. Techniques such as bounding box regression and non-maximum suppression (NMS) are applied here to polish these candidate areas. NMS helps in discarding redundant boxes, keeping only the most plausible facial regions.,
- Refinement Network (R-Net): After the initial identification, the regions detected by P-Net are refined further. These sections are cropped and resized before being passed through deeper convolutional networks that capture finer details. This phase increases precision by better distinguishing between facial and non-facial sections and refines the accuracy of the bounding box coordinates around the detected faces.,
- Output Network (O-Net): The final stage involves further adjustments to the bounding boxes. Here, more sophisticated classification and regression tasks are conducted, such as pinpointing facial landmarks like the eyes, nose, and mouth. This advanced stage aligns and localizes the detected face, resulting in a high-confidence output.

In comparative analyses, MTCNN has demonstrated superior performance over other face detection methods such as Depthwise Linear Inversion Precision (DLIP), conventional Convolutional Neural Networks (CNN), and Haar cascades in both accuracy and processing speed. Although DLIP and CNN offer good accuracy, they also come with limitations such as high data requirements and intensive computational needs, making them less feasible for real-time applications. On the other hand, Haar cascades, although faster, generally lag in accuracy. MTCNN's balanced approach with an emphasis on efficiency and precision has established its popularity across various applications such as security systems, mobile applications, and social media platforms for real-time facial recognition tasks [41].

3) Inception ResNet V1 as an Encoder Model: The Inception-ResNet V1 architecture is strategically implemented in our system as the encoder model, specifically engineered to convert 160x160x3 RGB images into 128-dimensional face encodings. By integrating convolutional layers with residual connections, this architecture addresses the vanishing gradient problem, a common challenge in training deep neural networks, thereby enhancing model performance in facial feature extraction [36]. The model comprises 22,808,144 parameters, with 22,779,312 being trainable and 28,832 non-trainable, optimizing the capture and interpretation of complex, high-dimensional facial characteristics.

Unlike traditional deep convolutional neural networks, Inception-ResNet V1 uniquely incorporates residual connections alongside conventional operations such as convolution,

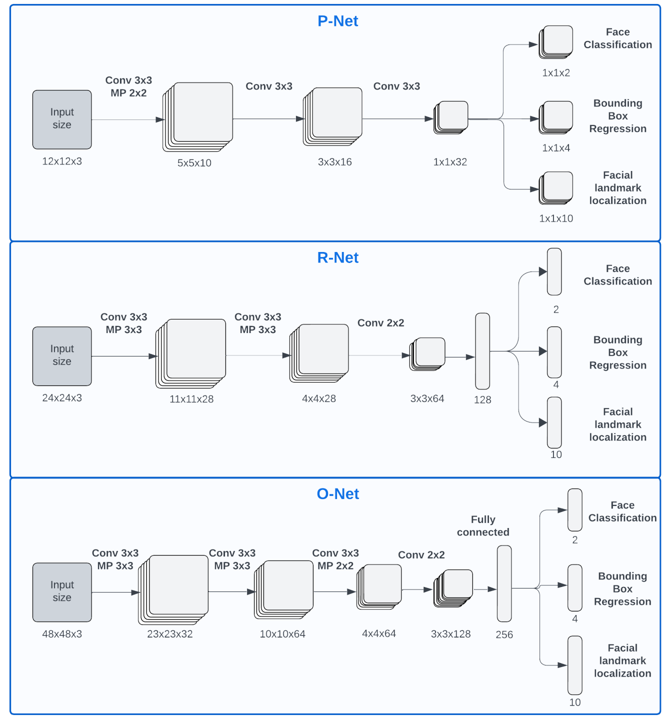

Fig. 2. Architecture of MTCNN (P-Net, R-Net, and O-Net), adoption and redrawn from [42].

pooling, activation, and fully connected layers. These residual pathways facilitate the gradient flow during learning, countering degradation and allowing seamless training across deeper network layers. This attribute extends its applicability to sophisticated image recognition tasks that require nuanced feature discernment and high levels of visual data interpretation [43].

Structured for performance efficiency, especially in mobile and embedded system applications, Inception-ResNet V1 remains computationally feasible for these resource-constrained platforms. With the growing emphasis on edge computing, this architecture offers an essential balance between performance output and power consumption.

The architecture's design also features Inception modules, which integrate various convolution filter sizes (1x1, 3x3, and 5x5) within a single layer. This array of layer configurations enables the model to process visual inputs at diverse scales efficiently, maximizing information extraction while maintaining resource economy [44]. The schematic representation of these Inception ResNet V1 blocks is depicted in Fig. 3.

A key aspect of the Inception-ResNet V1 design philosophy involves dimensionality reduction techniques. These techniques are applied through the strategic use of 1x1 convolutions preceding more computationally intensive layers (such as those involving 3x3 or 5x5 convolutions). This preventive measure curtails the exponential increase in computational demand by reducing the feature space dimensions before more extensive operations are executed. By adopting these advanced design principles, the Inception-ResNet V1 architecture adeptly balances accuracy with computational efficiency, making it an ideal choice for deep feature extraction tasks in image processing domains [45]. Fig. 3 illustrates these building blocks, highlighting their functional and structural attributes.

4) Optimizing the encoder with triplet loss: The encoder network, as depicted in Fig. 3, undergoes training to optimize facial feature extraction capabilities, employing a triplet loss function that utilizes three distinct types of triplets. These triplets, drawn from the LFW [35] and Selfies & ID Images datasets [31] datasets, consist of Anchor, Positive, and Negative faces, structured to refine the ability of the network to differentiate between distinct facial identities effectively.

a) Easy triplets: These include pairs where the distance between the Anchor and Positive images already exceeds the distance between the Anchor and Negative images by at least a margin ((α)). Such triplets generate zero loss because they already satisfy the desired separation criterion and thus do not contribute to further training efficacy.

b) Semi-hard triplets: Semi-hard triplets are characterized by the Anchor-Negative distance being greater than the Anchor-Positive distance, yet the Anchor-Positive distance is close enough to the Anchor-Negative distance such that both are within the margin's range. These triplets provide a non-zero loss, aiding in refining the network as they represent moderately challenging cases to learn from.

c) Hard triplets: The most instructive for training, hard triplets feature an Anchor-Negative distance that is less than the Anchor-Positive distance. These scenarios pose the greatest challenge to the network and are integral in actively pushing the boundaries of the model's discriminatory capabilities.

Fig. 4 illustrates the computational configuration, showing how the triplets are processed within the Encoder network to optimize the feature descriptive power.

The Triplet Loss function [46], detailed as follows and represented in Fig. 5, is mathematically structured:

$$\sum_{i=1}^{m} \max\left(d(\mathrm{a}^i, \mathrm{p}^i) - d(\mathrm{a}^i, \mathrm{n}^i) + \alpha, 0\right) \qquad (1)$$

This equation strategically manipulates the Euclidean distances to diminish the distance between each Anchor and its corresponding Positive (the same identity), while simultaneously enlarging the gap between the Anchor and the Negative (the different identity). Here, (m) represents the total number of triplets per batch, with each triplet defined by an anchor ((a)), positive ((p)), and negative ((n)). The (i)-th triplet's face encodings are generated through this sophisticated encoder network. The margin (α) is key to setting a baseline separation that ensures effective learning by elevating the discriminative potential of the embeddings. By normalizing face encodings to a unit L2 norm, the model treats all facial features equally, providing a consistent basis for distance comparisons.

This refined training process using triplet loss significantly boosts the Encoder's performance, enabling it to extract nuanced facial features effectively, which is crucial for accurate and reliable face recognition in diverse and dynamic environments such as during Hajj.

5) Siamese network for face recognition: Siamese networks excel in face recognition due to their high representational efficacy, achieving state-of-the-art performance with only 128 bytes per face. Ideal for few-shot learning, they require smaller datasets and demonstrate high accuracy, with a 99.63% success rate on the LFW dataset as shown in [47], and and Selfies & ID Images Dataset [31]. Their efficiency and low memory requirements make them suitable for mobile devices. Unlike typical CNNs, Siamese networks measure the distance between image pairs rather than classifying images into labels, adjusting to generate smaller distances for images with the same label and greater distances for different labels. [47].

D. Siamese Network Architecture for Facial Recognition

Facial recognition, a cornerstone of modern biometric systems, involves the comparison of two facial images to ascertain if they represent the same individual. This process requires both high accuracy and efficiency, especially when dealing with large datasets such as pilgrim images from passports during the Hajj. Fig. 6 illustrates the fundamental structure of the Siamese network model [48] used in this scenario.

The Siamese network architecture utilized for this purpose involves several critical steps:

1) Initial face processing: The initial stage involves detecting and cropping faces from input images using the MTCNN method. This approach guarantees precise isolation of faces from the overall image content, regardless of variations in angle, lighting, and facial expressions.,

2) Feature encoding: After face detection, the cropped facial images undergo normalization and are processed through the Inception ResNet V1 Encoder. This encoder converts visual facial characteristics into a 128-dimensional vector that represents the essential attributes of the face. This encoding is vital as it converts detailed facial traits into a form amenable to quantitative analysis and comparison.,

3) Distance computation and comparison: The face encodings are subjected to L2 normalization to ensure they are on a standard scale for feature comparison. The Siamese network then calculates the Euclidean distances between the encoding of the input face and those stored in the database. This distance measures similarity, where shorter distances signify greater similarity between pairs of faces.,

4) Threshold-Based identification: The recognition result is determined by a predefined threshold. If the smallest calculated distance between the input face and the database faces is below this threshold, the system recognizes that the faces belong to the same individual. In contrast, a distance that exceeds the threshold indicates different individuals. This threshold is essential in balancing false positive and negative rates, a critical factor in operational scenarios.

The choice of Siamese networks for this application is driven not only by their efficiency in few-shot learning environments, but also by their robust performance in variable conditions, a common challenge in systems deployed in dynamic settings like the Hajj. The combined use of MTCNN for precise face detection and Inception ResNet V1 for robust feature encoding ensures that the Siamese network delivers

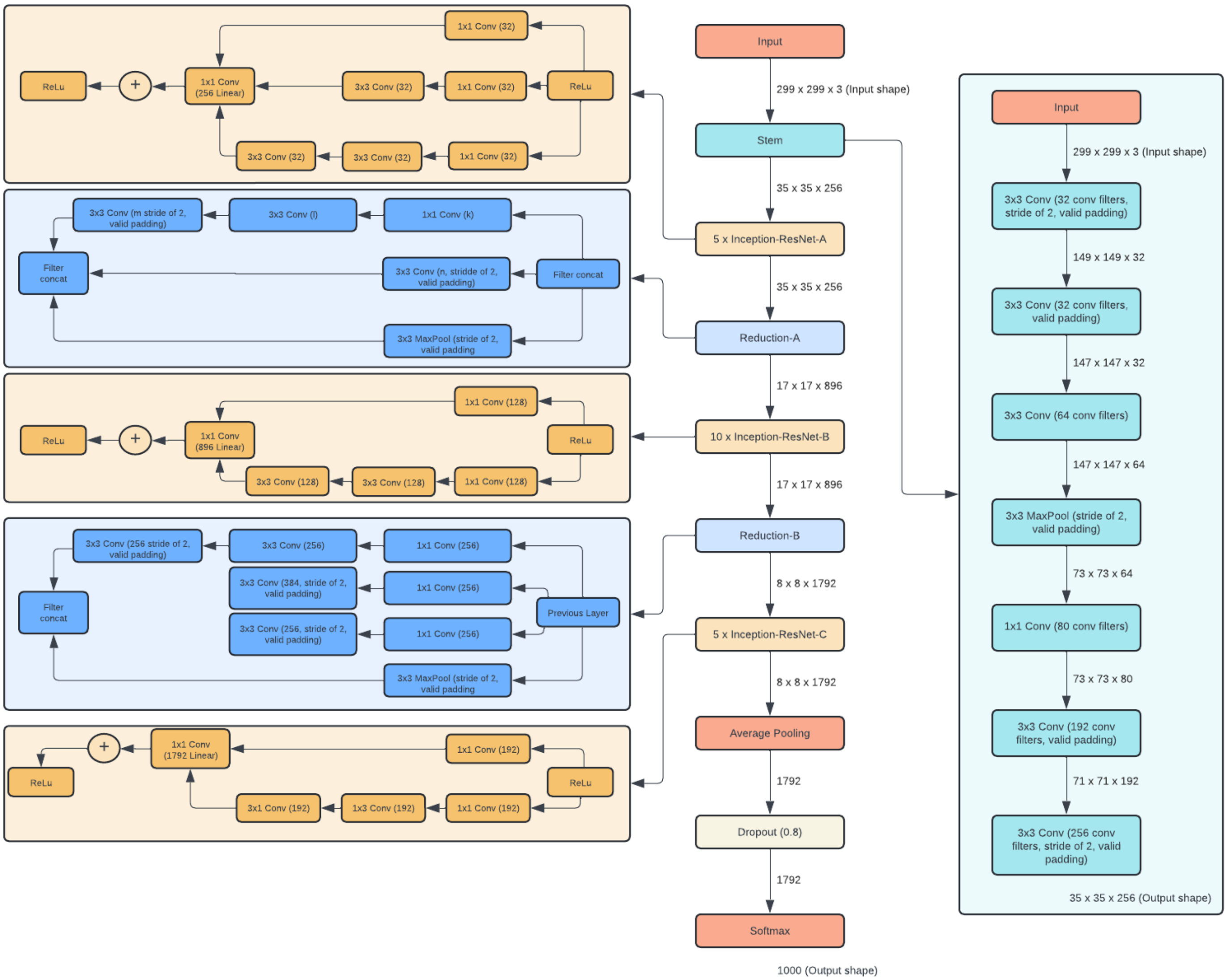

Fig. 3. Inception ResNet V1 blocks, adoption and redrawn from [44].

high accuracy and reliability under varied environmental conditions and across a wide range of facial characteristics [47]. This structured approach highlights the utility of the network in efficiently handling large-scale facial recognition tasks with a high degree of precision.

E. System Integration and Communication Protocols

The integration of the facial recognition system within MAHYA is a critical component, seamlessly merging front- and back-end processes to provide a robust real-time facial recognition capability. This section outlines the integration strategy that uses various technologies to facilitate communication and data transfer within the system.

The core facial recognition software is implemented in Python, harnessing the capabilities of the Flask framework to manage the back-end operations. Flask serves as a lightweight and versatile back-end server designed to handle API requests and responses efficiently. For the MAHYA application, Flask is configured to provide an API that bridges the Python-based facial recognition service with the Flutter-based front-end application.

To enable effective communication between these components, NGROK, a reverse proxy tool, is utilized to create a reliable and secure tunnel to the Flask application running on a local server. This setup involves:

1) HTTP Communication: The exchange between the front and back end is executed through HTTP requests, handled via the http package in Flutter [49]. This configuration transmits image data originating from the mobile application to the back-end for processing through the NGROK API endpoint. This setup promotes an efficient and clearly defined data transfer protocol [50].,

2) Image processing: Once images are received, the Flask server processes them to identify and verify faces using the previously mentioned pre-trained models. The processing entails extracting facial features from the images, encoding these

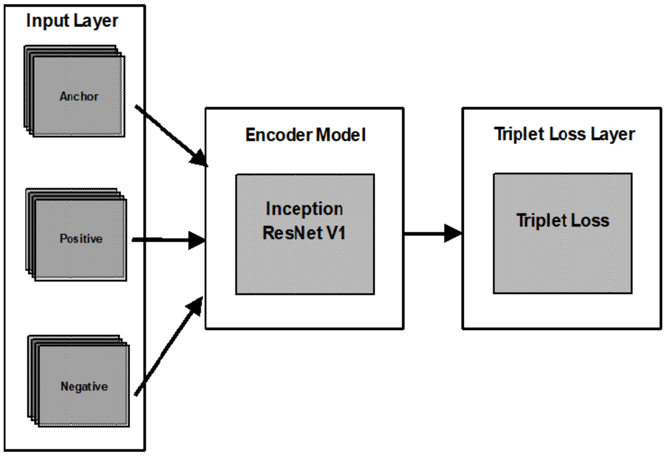

Fig. 4. Schematic diagram of the Encoder network including input layer, model, and triplet loss layer, adapted and redrawn from [36].

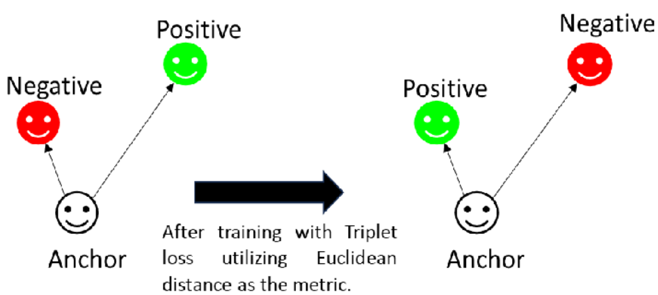

Fig. 5. Illustration of triplet loss mechanism, adapted and redrawn from [47].

features, and conducting similarity comparisons against faces stored in the database [51].,

3) Result communication: Upon completing the processing, the facial recognition outcomes are relayed to the Flutter application through the pre-established NGROK channel. This supports prompt visualization of recognition findings, enabling seamless real-time interaction and feedback within the app.

This integrated system architecture ensures seamless data flow from the point of capture on the mobile device to the processing logic on the server and then back to the mobile app for user interaction. Using Flask for back-end management, Python for processing, and NGROK for secure external connectivity, the system provides a highly efficient, secure, and responsive facial recognition service necessary for the dynamic environment of the Hajj pilgrimage. The robust communication setup supports high data integrity and quick response times, essential for effective deployment in critical use-case scenarios where speed and accuracy are paramount.

VI. Result

This subsection elucidates the operational interfaces of the MAHYA application, particularly designed for paramedic use. The interface is tailored to streamline patient care processes during the Hajj period, enhancing both efficiency and accuracy in medical interventions.

1) Patient scanning interface: The patient scanning feature constitutes a core functionality of the MAHYA application. This tool allows paramedics to swiftly capture a facial image of the patient, which is then processed through the integrated facial recognition system to verify the patient's identity against medical records stored in the database. The swift identification process facilitated by this feature is crucial in emergency situations, where time is of the essence. Accurate patient identification enables immediate access to medical histories, thereby enabling paramedics to administer the most appropriate and informed medical treatments. An illustrative depiction of the patient scanning interface is shown in Fig. 7.

2) Real-time medical history update interface: Another vital feature offered by the MAHYA application is the ability of paramedics to update medical records in real time. This interface supports the addition of new medical information and the modification of existing data, ensuring that patient records remain comprehensive and up-to-date. This real-time update feature is particularly valuable in the dynamic environment of the Hajj, where health conditions can evolve rapidly, and timely data revisions are crucial for the subsequent provision of care. The functionality of this interface is represented in Fig. 8.

These interfaces are designed with a focus on user-friendliness and rapid functionality to meet the high demands of the Hajj medical services. By providing essential features such as immediate patient scans and real-time updates, the MAHYA application significantly enhances the operational efficiency and effectiveness of healthcare providers in the field, ensuring that pilgrims receive the best possible medical attention quickly and accurately. These improvements directly contribute to better health outcomes and better management of medical resources during the pilgrimage.

A. MAHYA Facial Recognition System

The facial recognition system in the MAHYA application is driven by a Siamese network design, using the Inception ResNet V1 model. The key training parameters were as follows:

- Epochs: The number of complete passes through the training data set.
- Triplet Loss: A distance-based loss function that helps determine the similarity between the examples. The lower the loss, the better the effectiveness of the model in distinguishing distinct classes.
  The Triplet Loss is calculated using the following equation:

$$L = \sum_{i=1}^{N} \left[\left| f(x_i^a) - f(x_i^p) \right|^2 - \left| f(x_i^a) - f(x_i^n) \right|^2 + \text{margin} \right]_+$$

  where: (x_i^a) is the anchor input, (x_i^p) is the positive input (same class as anchor), (x_i^n) is the negative input (different class from anchor), ($f(x)$) is the feature embedding of input (x), (margin) is a predefined margin to maintain between positive and negative pairs, ($[z]_+$) denotes the positive part of (z) (i.e., ($\max(z, 0)$)).

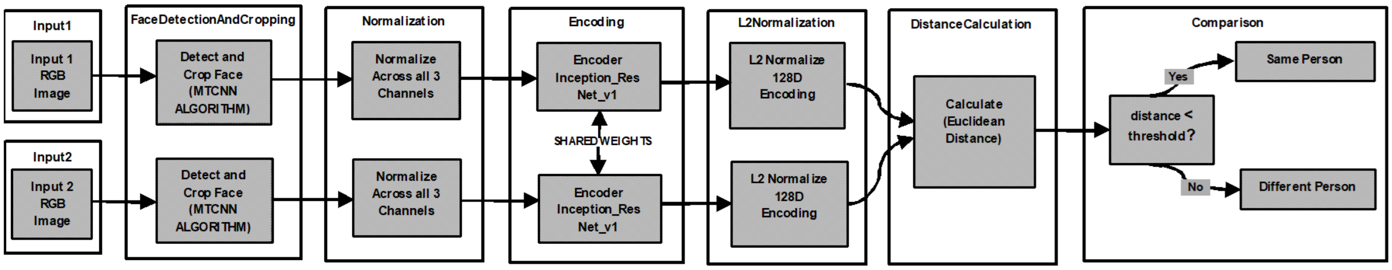

Fig. 6. Structure of the Siamese network model, adapted and redrawn from [36].

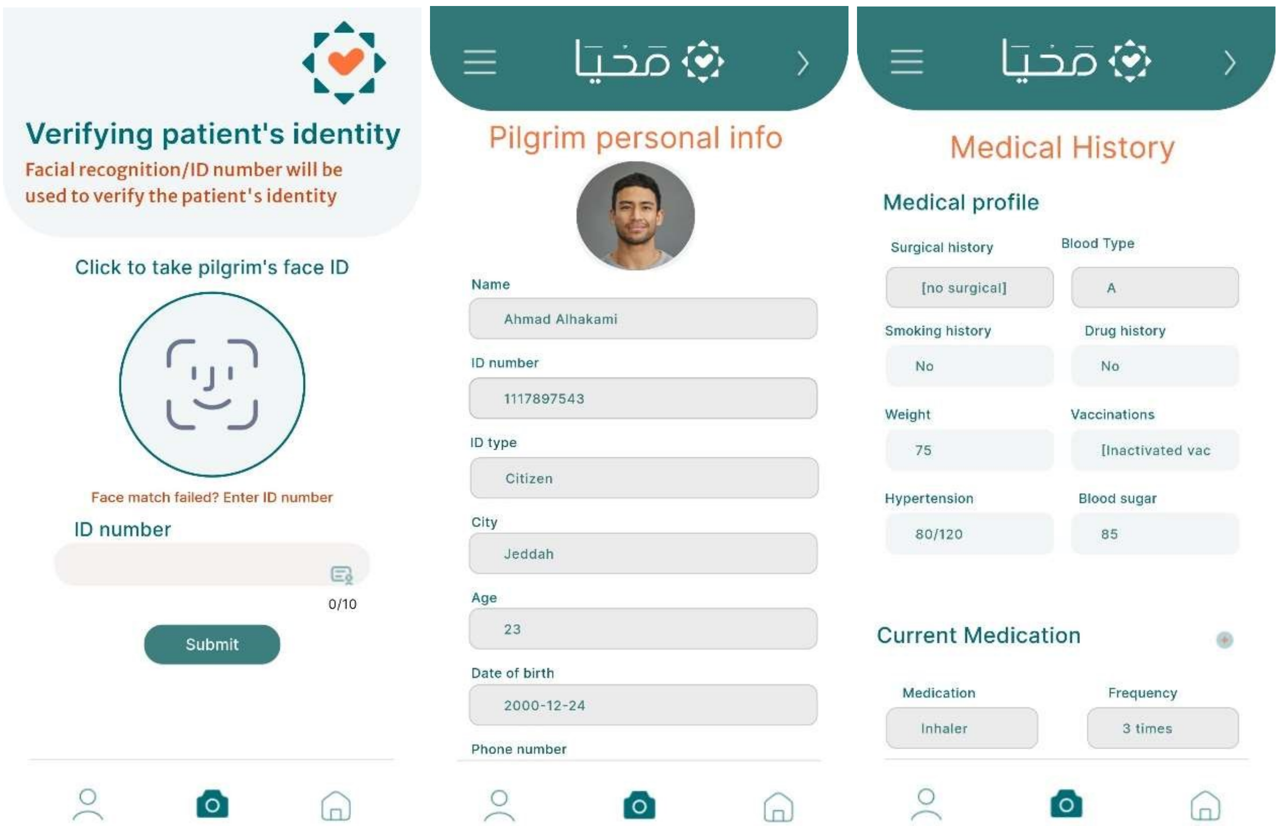

Fig. 7. MAHYA Interface includes pilgrim identification process, information, and medical history.

- Learning rate: The step size in each iteration while moving toward a minimum loss function. A higher learning rate might converge faster but risks overshooting, while a lower rate might converge slowly.
  The learning rate in many training scenarios is constant or adjusted according to a schedule. A common approach for adjusting the learning rate is the exponential decay:

$$\text{Learning Rate} = \text{Initial Rate} \times e^{-\text{decay rate} \times \text{epoch}}$$

  where: (Initial Rate) is the starting learning rate, (decay rate) is a hyperparameter controlling how quickly the learning rate decreases, (epoch) is the current epoch number
- Accuracy (%): The percentage of correctly predicted instances out of all predictions made. This is a direct measure of the performance of the model in the training set.
  Accuracy is calculated as the ratio of correctly predicted observations to the total number of observations:

$$\text{Accuracy}(\%) = \left(\frac{\text{Number of correct predictions}}{\text{Total number of predictions}}\right) \times 100$$

Table I displays the progression of the training performance of a deep learning model over various epochs, detailing Triplet Loss, Learning Rate, and Accuracy. The decrease in Triplet Loss alongside adjustments in Learning Rate and corresponding improvements in accuracy (%) demonstrates the increasing effectiveness of the model in feature discrimination and classification accuracy throughout the training process.

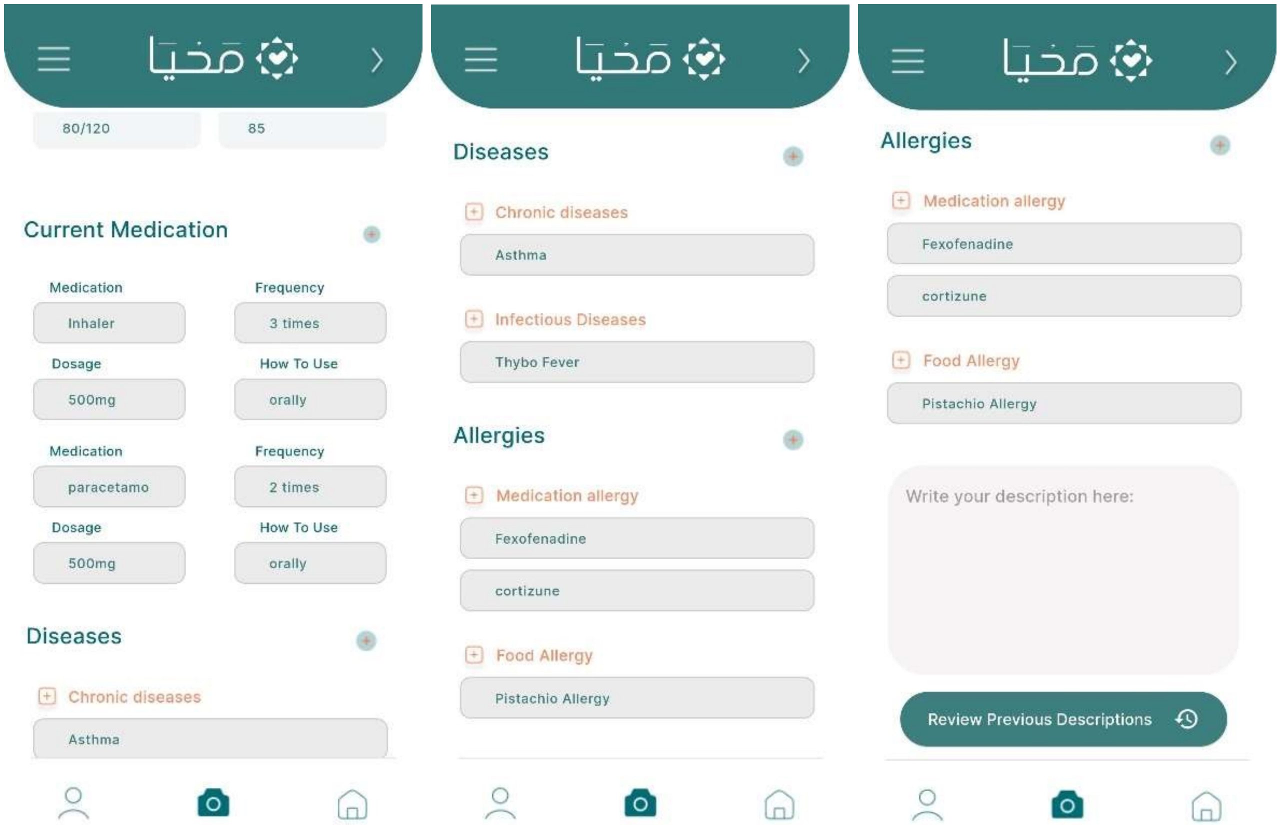

Fig. 8. Complete pilgrim medical history.

TABLE I. MODEL TRAINING PERFORMANCE METRICS OVER EPOCHS

Epochs	Triplet Loss	Learning Rate	Accuracy (%)
10	44.82335	0.01	52.3
20	35.8147077	0.01	64.5
30	21.63115	0.008	72.1
40	10.120723	0.008	79.8
50	4.134598	0.006	85.6
60	2.0523626	0.006	88.2
70	0.7735546	0.004	91.7
80	0.9250006	0.004	93.5
90	0.26632152	0.0001	95.8
95	0.084367274	0.0002	96.7
100	0.13581265	0.0005	97.4

The model exhibited a significant reduction in triplet loss from an initial 48.182335 to zero by the 95th epoch, indicating robust learning and convergence. In Fig. 9 the highlights of the loss curve are:

- Initial learning: A sharp decrease in loss within the first 10 epochs, reflecting rapid adaptation to data differences.
- Gradual refinement: A slower decline from the 10th to 60th epoch, demonstrating the model's ability to discern finer distinctions.
- Stabilization: Minimal fluctuations after the 60th epoch, indicating stability and resistance to overfitting.

The model successfully differentiated between images of the same person and different individuals; see Fig. 10. This is evidenced by significantly lower distance metrics for similar images compared to dissimilar ones; see Table II.

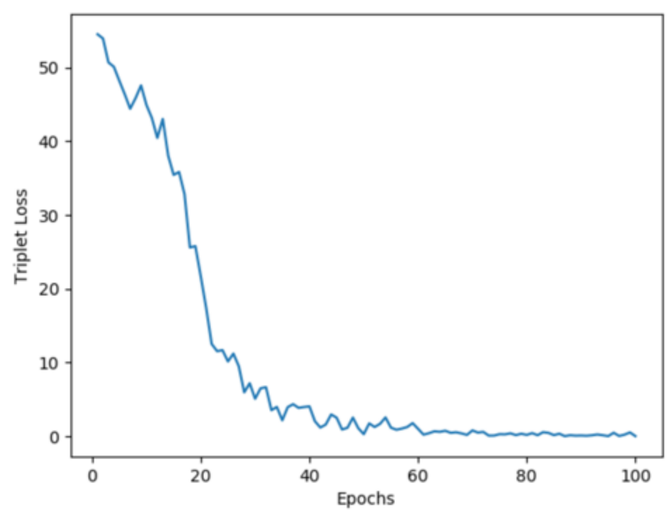

Fig. 9. Plotting triplet loss decline across 100 training epochs.

The dataset used for testing, as shown in Fig. 10, is the Selfies & ID Images Dataset [52].

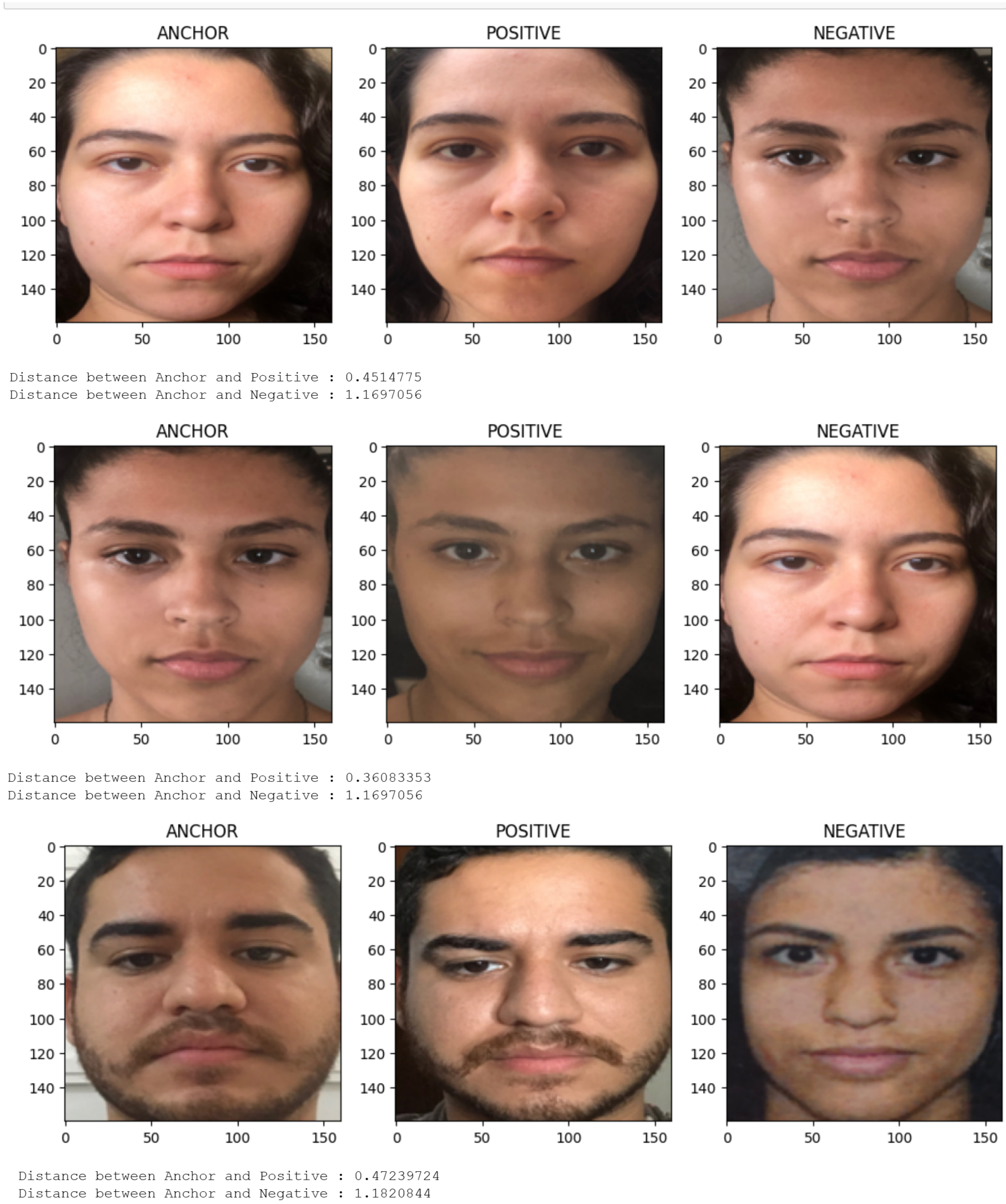

Fig. 10. Test data results of our model using preliminary dataset [31] showing triplet loss anchors and distance metrics.

TABLE II. DISTANCE METRICS FOR SIMILAR AND DISSIMILAR IMAGES

Similar mages	Dissimilar images
0.4514775	1.1697056
0.36083353	1.1697056
0.47239724	1.1820844

VII. DISCUSSION

The discussion surrounding the implementation and efficacy of the MAHYA application during the Hajj season encapsulates several critical aspects detailed below:

A. Technological Advancements and Integration

The introduction of MAHYA, a mobile application equipped with state-of-the-art facial recognition technology, marks a significant advancement in emergency healthcare management for Hajj pilgrims. Utilizing Inception ResNet V1 and Siamese algorithms, the app significantly enhances the identification process and quickens the retrieval of medical histories, thereby improving the efficiency of emergency medical responses.

B. Impact on Emergency Medical Care

MAHYA has a profound impact on emergency medical care, providing paramedics with immediate access to essential medical history data. This accessibility is crucial for making informed treatment decisions swiftly, thereby overcoming previous hurdles such as language barriers and the unavailability of medical histories. The integration of this technology has led to a notable reduction in response times and has increased the accuracy of medical services provided during the pilgrimage.

C. Security and Data Privacy

Given the sensitivity of accessing patient medical records, MAHYA incorporates robust security protocols to ensure data privacy and prevent unauthorized access. The application employs secure login mechanisms and restricts data retrieval to authenticated medical personnel only, thus upholding the confidentiality and integrity of the pilgrim's medical data.

D. Challenges and Limitations

Despite its achievements, the implementation of MAHYA faces certain challenges as any technological innovation. Issues such as data accuracy, facial recognition reliability in varying environmental conditions, and the continuous need for system and security updates are areas that require ongoing attention and improvement.

E. Advantages Compared to Current Systems

In comparison to existing systems [15], [53], [16], [40], the MAHYA application offers several distinct advantages. First, its use of the Inception ResNet V1 and Siamese network algorithms enhances facial recognition accuracy and speed, significantly surpassing traditional methods that may rely on more manual identification processes or lower-tech solutions. For instance, unlike systems that require extensive hardware setups or suffer from slower response times, MAHYA's mobile-based architecture ensures rapid access to medical records without the logistical burdens associated with such hardware dependencies.

Furthermore, the integration of MAHYA with the healthcare databases maintained by the Saudi Ministries of Health and Hajj and Umrah, combined with its real-time data update capabilities, provides a level of immediacy and accuracy not typically available in other systems. This is crucial in a high-stakes environment where timely medical interventions can mean the difference between life and death.

Moreover, the security features within MAHYA ensure the confidentiality and integrity of sensitive medical data, adhering to the highest standards of data protection. This contrasts with other models where security may not be as robust or well-integrated into the core system functionalities.

By focusing on these advantages, MAHYA not only sets a new standard for emergency medical care in the context of large-scale religious gatherings but also provides a replicable model for other emergency medical contexts where quick, reliable access to medical history is crucial.

Incorporating such a comparative analysis will clearly delineate MAHYA's unique contributions and its improvements over existing systems, further highlighting the significance of this research and its practical applications

VIII. Future Works

While the current implementation of the MAHYA application signifies a substantial advancement in emergency medical services, there are several avenues for further enhancement and research that could elevate its functionality and applicability. Future work could focus on integrating real-time location tracking technologies, which would enable paramedics to quickly locate and reach pilgrims in need of medical assistance. This integration could dramatically reduce response times and refine the application's utility in highly congested areas.

Additionally, exploring the integration of predictive analytics could offer another layer of innovation. By analyzing trends and previous medical incidents during Hajj, the system could potentially forecast areas or times of heightened medical risk, allowing preemptive deployment of resources and medical personnel. This proactive approach could transform emergency medical response from reactive to predictive, enhancing overall crisis management.

Another promising area of development involves expanding the application's adaptability to other large-scale international events, such as the Olympics or World Cup, where similar logistical and medical challenges may arise. Tailoring the application to meet the specific characteristics and needs of different events could help generalize the solution, providing a robust platform that can be utilized globally.

Lastly, further research into enhancing the privacy and security aspects of facial recognition technology within MAHYA is vital. Ensuring robust protection against data breaches and unauthorized access remains paramount, especially as the application scales and handles increasingly sensitive information.

By pursuing these directions, the MAHYA application can continue to evolve and assert its role as an indispensable tool in emergency medical services during large gatherings, ensuring that it remains at the forefront of technological innovation in healthcare.

IX. Conclusions

This study has successfully demonstrated the impactful implementation of the MAHYA application as a transformative tool in the emergency medical services landscape during the Hajj pilgrimage. By integrating advanced facial recognition technologies, specifically Inception ResNet V1 and Siamese networks, MAHYA has effectively addressed significant challenges such as language barriers and immediate access to medical histories. The application proved capable of enhancing the operational efficiency of emergency medical responses by facilitating rapid identification processes and access to crucial health information.

The adoption of MAHYA during the Hajj not only improved response times but also increased the accuracy and effectiveness of medical interventions. Its backend architecture, built on robust frameworks like Flask and Python, ensured seamless operation and integration, making it a reliable solution in the dynamic and demanding environment of large-scale religious gatherings. Additionally, the application's focus on data security has set a new benchmark in managing sensitive medical information under challenging conditions.

The successful deployment and positive outcomes associated with the MAHYA application underscore its potential as a scalable solution for other similar contexts. Its innovative approach to using mobile health technology in emergency medical situations presents a model that can be adapted and extended beyond the Hajj, highlighting its broad applicative possibilities.

Ultimately, MAHYA's contribution goes beyond mere technical achievement; it represents a significant step forward in humanitarian efforts, enhancing the safety and well-being of millions of pilgrims. The insights gained and the advancements made through this research provide a solid foundation for ongoing and future innovations in emergency medical care at mass gatherings.

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