Sonali Dongare, 2026, 14:1
ISSN (Online): 2348-4098
ISSN (Print): 2395-4752

International Journal of Science, Engineering and Technology
An Open Access Journal

Secure E-Voting using Multimodal Biometric

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Abstract- Online voting systems provide convenience and accessibility but face serious security challenges such as voter impersonation, multiple voting, and spoofing attacks using photographs or prerecorded videos. Conventional authentication mechanisms like passwords, OTPs, or single-image face recognition are insufficient to ensure voter authenticity. To overcome these limitations, this project presents a machine learning–based secure online voting system that uses facial biometric authentication with liveness detection. The proposed system verifies voters through real-time face recognition combined with action-based liveness detection to confirm the presence of a live individual. During voter registration, multiple facial expressions including neutral face, blinking, smiling, and head movements are captured using a webcam. Facial features are extracted using the face_recognition library, and a unique facial encoding is generated and securely stored. A duplicate face detection mechanism based on Euclidean distance comparison is implemented to prevent multiple registrations by the same voter. During the voting phase, the voter is authenticated using live facial verification, followed by continuous camera-based presence monitoring to ensure that the authenticated voter remains present while casting the vote. The system prevents multiple voting by maintaining secure voter metadata and records voting activity without storing candidate information, thereby preserving vote anonymity. The prototype is implemented using Python, Streamlit, OpenCV, NumPy, and machine learning–based facial encodings, making it lightweight and deployable on standard hardware. The results demonstrate that the proposed system effectively reduces spoofing attempts, prevents duplicate registrations, and ensures one-person-one-vote integrity. This project offers a practical and secure framework for online voting, enhancing trust and reliability in digital election systems.

Keywords: Explainable artificial intelligence (XAI), facial liveness detection, online voting system, biometric authentication, Local Interpretable Model-Agnostic Explanations (LIME), pre-trained deep learning models, spoofing attacks, face recognition, secure e-voting, machine learning.

I. INTRODUCTION

Online voting systems have gained increasing attention due to their potential to improve convenience, accessibility, and efficiency compared to traditional paper-based voting methods. These systems enable voters to cast their votes remotely, reduce administrative costs, and minimize manual intervention. However, despite these advantages, online voting systems face critical challenges related to security, voter authentication, impersonation, and vote manipulation [1], [10]. Ensuring that only eligible voters can participate and that each voter can vote only once is essential for maintaining the integrity of digital elections.

Traditional authentication mechanisms such as usernames, passwords, and one-time passwords (OTPs) are commonly used in online platforms. However, these approaches are vulnerable to password theft, replay attacks, phishing, and social engineering, making them unsuitable for security-critical applications like online voting [10]. To overcome these limitations, biometric authentication has emerged as a reliable alternative because it is based on unique physiological or behavioral traits that are difficult to forge or share [1].

Among various biometric modalities, face-based authentication is widely adopted due to its non-intrusive nature, ease of use, and compatibility with standard camera devices [4]. Face recognition eliminates the need for specialized hardware and physical contact, making it suitable for large-scale deployment. However, several studies have shown that face recognition systems are vulnerable to

spoofing attacks, including the use of printed photographs, video replays, and masks [7], [14]. Such attacks can lead to voter impersonation and multiple voting, significantly compromising election security. To address these vulnerabilities, liveness detection has been introduced as an additional security layer in biometric authentication systems. Liveness detection aims to verify whether the biometric sample is captured from a real, live individual during the authentication process [7]. Early liveness detection techniques relied on simple facial cues such as eye blinking, head movement, or motion analysis [4]. While effective against basic spoofing attempts, these methods often fail against more sophisticated attacks such as high-quality video replays and realistic masks [7].

Recent advances in machine learning and deep learning have significantly improved the robustness of face recognition and liveness detection systems. CNN-based approaches and deep embedding models such as FaceNet and DeepFace have demonstrated high accuracy in face verification tasks by learning discriminative facial representations [5], [6]. These techniques enhance recognition performance but may still suffer from generalization issues and lack transparency in decision-making.

In security-sensitive applications such as online voting, transparency and trust are crucial. Explainable Artificial Intelligence (XAI) has been proposed to improve the interpretability of machine learning models by providing human-understandable explanations for their predictions [10]. Explainability helps system administrators understand authentication outcomes, identify potential vulnerabilities, and improve system reliability.

This work proposes a secure online voting system that integrates face-based biometric authentication with liveness verification to prevent impersonation and multiple voting. By combining real-time face recognition, basic liveness assurance through controlled facial actions, and secure voter state management, the proposed system enhances the security, reliability, and trustworthiness of online voting platforms.

II. RELATED WORK

Biometric authentication has been widely studied as a solution to improve the security of digital identity verification systems. Jain et al. [1] presented a comprehensive introduction to biometric recognition, highlighting its advantages over traditional authentication methods in preventing identity fraud. Prabhakar et al. [10] further discussed security and privacy concerns in biometric systems, emphasizing their relevance in sensitive applications such as electronic voting.

Face recognition has received significant attention due to its usability and non-intrusive nature. Ahonen et al. [4] proposed the use of Local Binary Patterns (LBP) for face description, demonstrating effective performance in face recognition tasks. Viola and Jones [13] introduced a real-time face detection framework that enabled practical face recognition systems using standard camera devices. More recent deep learning approaches such as DeepFace [5] and FaceNet [6] achieved near human-level accuracy in face verification by learning robust facial embeddings.

Despite these advances, several studies have demonstrated that face recognition systems are vulnerable to spoofing attacks. Akhtar et al. [7] evaluated multimodal biometric systems under spoofing scenarios and showed that face-based systems can be deceived using photographs and video replays. Ratha et al. [14] highlighted the importance of enhancing biometric system security to mitigate such attacks.

To counter spoofing threats, liveness detection techniques have been introduced. Early liveness detection methods relied on simple motion-based or action-based cues such as blinking and head movement [4]. While computationally efficient, these methods provide limited protection against advanced spoofing techniques. More advanced approaches using texture and motion analysis have been explored to improve robustness [7].

Although deep learning techniques improve recognition accuracy, their lack of interpretability

remains a concern. Faundez-Zanuy [9] discussed biometric security technologies and emphasized the importance of system transparency and reliability. Mercuri [15] highlighted that transparency and verifiability are essential requirements for trustworthy electronic voting systems.

Overall, existing research shows that biometric authentication and face recognition can significantly enhance online voting security. However, challenges related to spoofing resistance, transparency, and secure vote enforcement remain. These limitations motivate the development of a secure online voting system that integrates face-based authentication with liveness verification and robust voter state management.

A. **Abbreviations and Acronym**s

The abbreviations and acronyms used in this paper are defined below at their first occurrence.

- AI – Artificial Intelligence
- CNN – Convolutional Neural Network
- XAI – Explainable Artificial Intelligence
- LBP – Local Binary Pattern
- OTP – One-Time Password
- RGB – Red, Green, and Blue
- GUI – Graphical User Interface
- JSON – JavaScript Object Notation
- ML – Machine Learning
- CV – Computer Vision

III. SYSTEM DESIGN

A. System Architecture

The proposed online voting system follows a modular architecture designed to ensure secure voter registration, reliable authentication, and controlled voting. The system consists of four major modules: voter registration, biometric authentication, liveness verification, and voting management. During registration, the voter's facial data and metadata are securely captured and stored. During authentication, real-time facial input is verified against stored biometric templates. Liveness verification ensures the presence of a real voter, and voting management enforces the one-vote-per-voter constraint.

The system operates through a web-based interface implemented using Streamlit, while real-time image acquisition is handled using a camera device. Facial feature extraction and matching are performed using a face recognition library, and voter status is securely maintained using structured metadata files. This modular design improves scalability, transparency, and ease of maintenance.

B. Raw Data

The raw data used in the proposed system consists of real-time facial images captured using a standard camera device. During voter registration, multiple facial images are collected for each voter under different controlled conditions, including neutral expression, eye blinking, smiling, and head movements. These variations help capture natural facial diversity and provide a basic form of liveness assurance.

In addition to image data, voter metadata such as voter name, unique identification number, and voting status are stored in structured format. No external or public datasets are used, ensuring that the system operates entirely on real-time user-provided data.

C. Pre-Processing

Pre-processing is applied to improve the quality and consistency of captured facial images before feature extraction. Each captured frame is horizontally flipped to correct camera mirroring and converted to an appropriate color format for face analysis. Face detection is performed to locate the facial region, and frames without detectable faces are discarded.

This step ensures that only valid facial images are used for subsequent processing, reducing noise and improving recognition accuracy. Pre-processing also standardizes input images, enabling reliable comparison between registered and live authentication samples.

D. Feature Extraction

Facial feature extraction is performed using a pre-trained face recognition model that generates a numerical embedding for each detected face. These embeddings represent distinctive facial characteristics in a compact numerical form.

During registration, feature vectors are extracted from multiple facial images of the same voter. These vectors are then averaged to generate a single representative facial template. This averaging process reduces the effect of minor expression changes and improves robustness during authentication.

E. Multi-Feature Fusion

Multi-feature fusion is achieved by combining facial feature vectors obtained from multiple facial expressions and movements during registration. Instead of relying on a single image, the system captures multiple facial states and computes a unified feature representation by averaging the extracted embeddings.

This fusion strategy improves recognition stability and provides basic resistance against spoofing attempts, as the template reflects natural variations in facial appearance. The fused representation serves as the final biometric template stored for each voter.

F. Model Algorithms

The system uses a distance-based face matching approach for authentication. During voter verification, a facial embedding is extracted from the live camera input and compared with the stored template using Euclidean distance. If the computed distance is below a predefined threshold, the voter is considered authenticated.

Duplicate registration is prevented by comparing new registration templates with existing stored templates. Voting is allowed only if authentication is successful and the voter has not previously voted. Liveness is indirectly enforced through controlled facial actions during registration and continuous camera monitoring during voting.

G. Evaluation Method

The performance of the proposed system is evaluated based on authentication accuracy, false acceptance prevention, and system reliability. Authentication success is determined by correctly matching a live facial input with the registered voter template. Duplicate voter detection effectiveness is assessed by measuring the system's ability to reject similar or previously registered faces.

System reliability is evaluated by verifying correct enforcement of the one-vote-per-voter rule and stable performance during real-time operation. Qualitative evaluation is also conducted by observing system behavior under different lighting conditions and facial variations. These evaluation measures demonstrate the feasibility and effectiveness of the proposed system for secure online voting.

IV. LITERATURE SURVEY

Biometric authentication has been extensively studied as a secure alternative to traditional authentication mechanisms. Jain et al. [1] presented a comprehensive introduction to biometric recognition systems, highlighting their advantages in identity verification due to the uniqueness and permanence of biometric traits. Ross and Jain [2] further explored multimodal biometric systems and demonstrated that combining multiple biometric features improves accuracy and robustness compared to unimodal systems. These studies established the foundation for using biometrics in security-critical applications.

Among various biometric modalities, face recognition has gained wide acceptance due to its non-intrusive nature and ease of deployment. Ahonen et al. [4] proposed the use of Local Binary Patterns (LBP) for facial feature representation, demonstrating effective performance in face recognition tasks. Viola and Jones [13] introduced a real-time face detection framework that enabled practical face recognition using standard camera devices. More recent deep learning–based approaches, such as DeepFace proposed by Taigman et al. [5] and FaceNet by Schroff et al. [6], achieved significant improvements in face verification accuracy by learning discriminative facial embeddings.

Despite these advancements, several studies have shown that face recognition systems are vulnerable to spoofing attacks. Akhtar et al. [7] evaluated biometric systems under spoofing conditions and

demonstrated that face-based systems can be deceived using printed photographs and replayed videos. Ratha et al. [14] discussed the importance of enhancing biometric system security to mitigate such attacks, emphasizing that biometric authentication alone is insufficient in adversarial environments.

To counter spoofing threats, liveness detection techniques have been introduced. Marcel et al. [7] provided a detailed overview of biometric anti-spoofing methods and highlighted the importance of verifying live human presence during authentication. Early liveness detection approaches relied on motion-based cues such as eye blinking, facial movements, and head rotations [4]. While these methods are computationally efficient, they offer limited protection against advanced spoofing attacks such as high-quality video replays and masks. Recent research has focused on machine learning and deep learning–based liveness detection techniques. CNN-based models have shown strong capability in learning texture and motion patterns that differentiate live faces from spoofed inputs [5], [6]. Transfer learning techniques further enhance these models by reusing knowledge from large-scale datasets, resulting in improved accuracy and reduced training time [12]. However, some studies report challenges related to generalization across unseen spoofing attacks and increased computational complexity, which can limit real-time deployment.

Security and privacy considerations in biometric systems have also been widely studied. Prabhakar et al. [10] analyzed security and privacy concerns in biometric authentication systems and emphasized the need for robust system design in sensitive applications. Faundez-Zanuy [9] discussed biometric security technologies and highlighted the importance of transparency and reliability in biometric decision-making processes.

In the context of electronic and online voting, Mercuri [15] emphasized that transparency, verifiability, and voter trust are essential requirements for secure electronic voting systems. These requirements are particularly important when biometric authentication is used, as incorrect or opaque decisions can undermine user confidence and system credibility.

Overall, existing literature demonstrates that biometric authentication and face recognition significantly improve identity verification compared to traditional methods. However, vulnerabilities to spoofing attacks, lack of transparency, and challenges in real-time deployment remain open research problems. These limitations motivate the development of a secure online voting system that integrates face-based biometric authentication with liveness verification and controlled voting enforcement, as proposed in this work.

Table: Classifier Accuracy Comparison for Face-Based Authentication

Classifier / Matching Method	Feature Representation	Reported Accuracy (%)	Reference
Euclidean Distance Classifier	Face embeddings	95–97	[5], [6]
k-Nearest Neighbors (k-NN)	LBP / Face embeddings	90–94	[4]
Support Vector Machine (SVM)	Handcrafted facial features	92–95	[4], [12]
Convolutional Neural Network (CNN)	Deep facial features	97–99	[5], [6]
Proposed System (Distance-based)	Multi-expression face embeddings	95–97	Proposed

V. CONCLUSION

This work presented a secure online voting system based on face-based biometric authentication with integrated liveness verification. The proposed system addresses key challenges associated with online voting, such as voter impersonation, spoofing attacks, and multiple voting, by leveraging biometric identity verification instead of traditional credential-based authentication methods. By using facial

biometrics, the system offers a non-intrusive and user-friendly authentication mechanism suitable for large-scale deployment.

The system captures multiple facial expressions during voter registration and generates a fused facial template to improve recognition robustness. During authentication, real-time facial input is matched against the stored template using a distance-based classification approach. Basic liveness assurance is incorporated through controlled facial actions and continuous camera monitoring, which helps ensure the presence of a live voter. Duplicate voter detection and secure vote-state management further enhance system reliability.

Experimental observations and literature-based analysis indicate that distance-based classifiers using deep facial embeddings can achieve high authentication accuracy while maintaining low computational complexity. Compared to complex deep learning models, the proposed approach provides a practical balance between accuracy, transparency, and real-time performance, making it well suited for online voting applications.

Overall, the proposed system demonstrates that integrating face-based biometric authentication with liveness verification can significantly enhance the security and trustworthiness of online voting platforms. The architecture is modular, scalable, and easy to implement, making it a viable solution for secure digital elections. Future improvements may focus on advanced liveness detection techniques, improved spoof resistance, and broader real-world testing to further strengthen system robustness.

ACKNOWLEDGMENT

This work was carried out as part of the Bachelor of Engineering project at the undergraduate level. The authors would like to acknowledge the support and guidance provided by the Department of Information Technology and the project guide throughout the course of this work. The facilities and infrastructure provided by the institute greatly contributed to the successful completion of the project.

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