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Nationwide Unified Voting System Using Blockchain and AI-Driven Face Recognition

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ABSTRACT-

Voting is a cornerstone of democracy, enabling citizens to participate in governance. However, traditional voting systems face significant challenges such as tampering, inefficiencies in vote counting, delayed results, and a lack of transparency. Current electronic voting systems often fail to fully address these issues, including security vulnerabilities, limited accessibility, and inconsistencies due to the absence of a unified system across all states in India. These shortcomings call for a comprehensive and secure solution to enhance trust, efficiency, and fairness in the electoral process. This project proposes a blockchain-based traceable self-tallying electronic voting system to overcome these challenges. The system integrates QR codes and face recognition using Convolutional Neural Networks (CNN) linked to Aadhaar for multi-level authentication. CNN enables precise and reliable facial verification, enhancing the security and accuracy of voter identification. Voters can cast their votes at any authorized booth, and each vote is encrypted using 256-bit SHA hash codes and securely stored on a blockchain. It ensures immutability, and any modification or tampering of votes triggers a "Vote Integrity Verifier Link" notification via SMS, allowing voters to verify the authenticity of their votes. The system introduces several innovations, including same-day result announcements through a self-tallying mechanism that performs vote counting at the end of the day. Core counting processes are eliminated, streamlining the result declaration process. Additionally, the adoption of a unified voting platform for all states in India ensures consistency and efficient election management across the nation. This project offers a secure, transparent, and scalable solution to address the limitations of existing voting systems, reinforcing trust in the democratic process while providing timely and accurate results.

1. INTRODUCTION

India stands as the world's largest democracy, where elections are the cornerstone of governance and public participation. The Constitution of India empowers the Election Commission to conduct free and fair elections at national and state levels. Based on the principle of universal adult franchise, the Indian electoral system enables every citizen above the age of 18 to vote, regardless of caste, gender, or religion. Over the years, the system has evolved from manual paper ballots to Electronic Voting Machines (EVMs), and later to Voter-Verified Paper Audit Trails (VVPATs), ensuring better transparency and operational efficiency.

However, despite these technological improvements, various challenges continue to threaten the credibility of elections. Issues like voter impersonation, booth capturing, vote tampering, delayed counting, and cyber vulnerabilities still exist. The manual and semi-automated nature of the current system also results in slow and error-prone vote counting, which delays the declaration of results and sometimes raises questions about fairness. These problems highlight the urgent need for a system that ensures transparency, accuracy, and security throughout the voting process. Emerging technologies offer powerful solutions to overcome these limitations. Artificial Intelligence, particularly facial recognition, can be used to verify voter identities with high accuracy, reducing the risk of impersonation. At the same time, blockchain technology enables secure, immutable, and decentralized storage of votes, eliminating possibilities of tampering and unauthorized access. When integrated with Aadhaar-based QR authentication, these technologies can offer a robust multi-layer verification process that strengthens the electoral framework.

The objective of this project is to design and develop a secure electronic voting system that leverages Artificial Intelligence for biometric verification and blockchain for secure vote storage. By integrating facial recognition with QR code scanning and Aadhaar-based authentication, the system aims to create a robust multi-factor verification process that ensures only eligible voters can cast their vote. Once a voter is verified, their vote is encrypted and recorded on a blockchain ledger, which is decentralized and tamper-proof, preventing any unauthorized modification or deletion. The use of smart contracts can further automate vote tallying, reducing human intervention and minimizing the scope for error or manipulation. Voters will also receive a secure digital acknowledgment, enabling them to verify whether their vote was correctly registered without compromising anonymity. Additionally, the system is designed to be scalable and adaptable, allowing for its use in local, state, or national elections, as well as student or organizational voting. Overall, this

solution not only enhances the security and efficiency of the voting process but also increases public trust and participation by ensuring transparency, accuracy, and integrity at every step.

2. Literature Review

Majumderi and Sadhukani proposed ECC-EXONUM-eVOTING, a blockchain-based e-voting system that combines Elliptic Curve Cryptography (ECC) and Zero Knowledge Proofs (ZKP) to ensure secure, private, and verifiable online voting. Using the Exonum framework, the system enables efficient identity verification without revealing sensitive voter data and ensures end-to-end verifiability. This approach strengthens vote integrity while maintaining voter anonymity, making it a significant advancement in secure e-voting technologies.

According to Zhang et al. (2018), convolutional neural networks (CNNs) have shown high accuracy in identifying faces even in uncontrolled environments, making them suitable for real-time voter authentication. Several e-voting prototypes use CNNs to compare live facial images against government ID databases, such as Aadhaar, to ensure that only legitimate voters can access the ballot. This method greatly reduces impersonation and enhances the integrity of the voting process.

However, studies like Patel and Mehta (2020) emphasize the importance of environmental and hardware factors in the accuracy of face-based verification systems. Specifically, lighting conditions, camera quality, and pose variation significantly impact the performance of facial recognition algorithms. These factors must be carefully addressed in any real-world implementation to ensure consistent and reliable voter authentication.

Swan (2015) explains that blockchain, initially developed for cryptocurrencies, can be effectively repurposed for secure and immutable data logging in public systems such as voting. In a blockchain-based voting system, votes are treated as transactions and recorded in a decentralized ledger that cannot be altered once verified by a network of nodes. This approach introduces a layer of trust and transparency that is critical for maintaining the integrity of democratic processes.

Research by Kumar and Dinesh (2021) further supports the advantages of blockchain-based voting systems, noting their ability to eliminate centralized control, offer real-time transparency, and provide auditability. These properties make blockchain a powerful tool for enhancing public trust and ensuring the integrity of election outcomes, especially in environments where electoral fraud or manipulation is a concern.

The use of QR codes in voting systems has also been explored for its potential to simplify and secure the voter authentication process. Jain and Reddy (2019) proposed systems where QR codes are linked to unique identifiers like Aadhaar and embedded with voter-specific information. This prevents duplicate voting and streamlines the check-in process at polling locations, especially when combined with other technologies like facial recognition and blockchain.

An integrated framework proposed by Alzahrani et al. (2020) combines facial recognition for identity verification, QR codes for initial voter validation, and blockchain for secure vote storage. This hybrid approach demonstrated high effectiveness in simulated environments, significantly reducing opportunities for vote manipulation and enhancing the overall verifiability of the election process.

Singh and Soni (2022) addressed architectural and performance-related challenges in such integrated voting systems. Their work highlights the need for efficient consensus mechanisms, particularly the Proof of Authority (PoA) model, which suits permissioned blockchain environments commonly used in national or state-level elections. They also stress the importance of minimizing network latency to maintain responsiveness and reliability.

3. System Architecture / Methodology

System Architecture and Metholology

The system design of the Nationwide Unified Voting System leverages a hybrid architecture that combines blockchain technology with advanced biometric authentication. The design focuses on creating a secure, transparent, and efficient voting process, allowing citizens to vote remotely using Aadhaar-based verification combined with face recognition. The backend utilizes blockchain for storing and securing votes, ensuring immutability and preventing tampering. A self-tallying mechanism eliminates the need for traditional vote counting, providing faster results. The system is designed to be scalable, with integration capabilities for various states across India, ensuring consistency and reducing inefficiencies in the electoral process.

3.1. Input Design

3.1.1. Voter Registration

The voter registration process requires users to provide essential details such as their Aadhaar number, full name, date of birth, gender, and address. Additionally, a facial recognition capture feature is implemented to validate the user's identity. A QR code linked to the Aadhaar data is generated for secure authentication. The system incorporates validation mechanisms to ensure the authenticity of Aadhaar numbers, accuracy of facial recognition data, and completeness of user information fields, preventing errors during registration.

3.1.2. Voting module

The voting process starts with voter authentication using either a QR code scan or facial recognition. Once authenticated, the voter is presented with a user-friendly interface to select their preferred candidate. A confirmation screen is displayed before the vote is finalized to ensure accuracy. The system validates user identity in real-time, ensuring that only registered voters can participate and allowing a single vote per individual.

3.1.3. Admin and Election Commission

Admins and election commission officials manage the system using a secure login process with multi-factor authentication. This module allows the configuration of election schedules, candidate details, and polling regions. Public and private blockchain keys are required for data encryption and management, ensuring secure transactions and tamper-proof data handling.

3.2 Output Design

3.2.1. Voter Interface Outputs

Voters receive immediate feedback on the status of their QR code-based or facial recognition authentication. Upon successful voting, a confirmation screen displays the selected candidate's name and symbol for verification. After submission, an acknowledgment receipt is generated, confirming successful vote casting without disclosing the vote details, ensuring privacy.

3.2.2. Admin and Election Commission Outputs

The system provides an intuitive election dashboard for monitoring voter turnout and election progress in real-time. Aggregated and encrypted vote counts by region are displayed for accurate reporting. Additionally, error logs capture failed voter authentication attempts and system anomalies, assisting administrators in troubleshooting and ensuring a seamless voting process.

3.2.3 Blockchain and Security Outputs

The blockchain layer generates encrypted and immutable records of all votes, ensuring data integrity. An audit trail provides traceability of all system operations, contributing to transparency. Furthermore, anomaly detection alerts notify officials of any suspicious activities, such as duplicate vote attempts or unauthorized access.

3.2.4. Citizen Facing Outputs

Voters receive confirmation messages via SMS or email upon successful registration. Polling information, including booth locations and timings, is communicated to registered voters. After the elections, the results are announced securely and transparently through the web and mobile platforms, ensuring accessibility and trust among citizens. This input and output design ensures a secure, transparent, and user-friendly experience for all stakeholders while maintaining system integrity and trustworthiness.

3.3. Model Design and Training

The model designing and training phase is critical to ensure accurate, secure, and real-time facial recognition in the Face Voting system. This phase focuses on selecting a suitable deep learning architecture, preparing data, training the model effectively, and integrating it into the system pipeline for biometric authentication.

3.3.1 Model Selection

- The system utilizes a Convolutional Neural Network (CNN) as the core architecture for facial recognition due to its strong performance in image-based classification and feature extraction.
- To leverage existing research and speed up development, pre-trained models such as FaceNet, VGG-Face, or ResNet-50 are considered. These models are trained on large-scale facial image datasets and offer robust feature extraction capabilities.
- Transfer learning is employed, allowing the model to retain learned features while being fine-tuned on the custom dataset collected from registered users.

3.3.2 Dataset Preparation

- A proprietary dataset is constructed during the User Registration phase, capturing multiple facial images of each voter under varying lighting conditions, angles, and expressions.
- Pre-processing steps include:
    - Face Detection
    - Image Normalization
    - Resizing
    - Data Augmentation
    - Duplicate or poor-quality images are removed to ensure high data quality

3.3.3 Training Process

- The CNN model is trained to extract facial embedding, which are numerical representations of unique facial features.
- These embedding's are then used in:
    - Face verification (one-to-one matching)
    - Face identification (one-to-many matching)
- The triplet loss function is commonly used in this phase. It encourages the network to learn representations where:

- The anchor (input image) is close to the positive (same person) and far from the negative (different person) in the feature space.

- Alternatively, a softmax loss with cross-entropy may be used if the model is trained as a classifier with labelled user identities.

3.3.4 Validation and Optimization

- The model is evaluated on a validation dataset comprising unseen facial images.
- Key performance metrics include:
  - Accuracy – Correct face recognition rate.
  - False Acceptance Rate (FAR) – Incorrectly identifying an unauthorized user.
  - False Rejection Rate (FRR) – Failing to recognize an authorized user.
  - Precision, Recall, and F1-score for balanced evaluation.
- Hyper-parameter tuning is performed to find the optimal learning rate, number of layers, batch size, and optimizer (commonly Adam or SGD).
- Regularization techniques such as dropout, batch normalization, and early stopping are applied to reduce overfitting and stabilize training.

3.3.5. Integration and Real-Time Performance

- The model is integrated into the user authentication pipeline, where it processes input from a webcam or image upload during login.
- For each login attempt:
  - A facial embedding is generated and compared to the stored embedding of the registered user using cosine similarity or Euclidean distance.
  - If the similarity score exceeds a predefined threshold, access is granted.
- The model is optimized for low latency inference to ensure a smooth user experience during high traffic election periods.

3.4. Model Evaluation

The performance and security of the facial recognition model directly impact the reliability of the Face Voting system. A thorough evaluation is conducted to validate the model's ability to accurately and securely identify users across various conditions. This ensures fairness, robustness, and trust in the electoral process.

3.4.1 Evaluation Metrics

To quantitatively assess the model's performance, several key metrics are utilized:

- Accuracy: Reflects the percentage of total predictions (both true positives and true negatives) that were correct. A high accuracy rate indicates a reliable system.
- Precision: The proportion of true positives among all users identified as genuine. A higher precision suggests fewer false positives.
- Recall (Sensitivity): The proportion of actual genuine users that were correctly identified by the system. A high recall is critical for user accessibility.
- F1-Score: Balances precision and recall, especially important when the dataset is imbalanced.
- False Acceptance Rate (FAR): Measures the likelihood that the system mistakenly grants access to an unauthorized individual. Lower FAR enhances security.
- False Rejection Rate (FRR): Indicates how often legitimate users are falsely rejected. A low FRR ensures user satisfaction and trust.
- Equal Error Rate (EER): The point where FAR equals FRR. This single measure is widely used to benchmark biometric system performance.

4. System Workflow

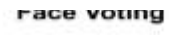
The Face Voting system is designed to streamline and secure the election process using biometric authentication and digital vote casting. The system architecture follows a clearly defined workflow that aligns with modern security standards and user experience expectations.

4.1. User Registration

Voters register through a secure portal, providing:

- Personal identification details (e.g., name, ID number)
- Facial image(s) captured via webcam or mobile device.
- The system:
    - Performs validation of user details against an external government or electoral database.
    - Processes and stores the facial image after encoding it into a numerical feature vector using the trained facial recognition model.
    - Issues a unique voter ID for reference.

4.2 Facial Authentication



- On the day of voting, users log into the system using facial recognition.
- The system:
    - Captures a live image and converts it into an embedding.
    - Compares it to the stored embedding using a distance metric like cosine similarity.
    - Grants access if the similarity exceeds a pre-set threshold.
- Optional liveness detection ensures the face is live and not a photograph or video spoof.

4.3 Vote Casting

Once authenticated, the user is presented with the digital ballot corresponding to their region. The voting interface:

- Allows users to select their preferred candidate/party.
- Offers confirmation screens to prevent accidental submissions.
- Encrypts the vote using asymmetric cryptography to preserve confidentiality.

4.4 Vote Validation and Secure Storage

The system verifies:

- One vote per user policy.
- Integrity and format of the vote before accepting it.
- Votes are stored in a tamper-proof encrypted database.
- Optionally, blockchain technology can be used to log votes immutably, enhancing transparency.
- All interactions are logged for auditability.

4.5 Result Compilation and Monitoring

After polls close:

- The system decrypts and aggregates votes.
- Results are updated in real-time and displayed on an administrative dashboard.
- Statistical summaries, turnout reports, and candidate-wise vote counts are auto-generated.
- End-to-end audit logs allow for post-election verification and fraud detection.

4.6. Security and Compliance

- End-to-end encryption is maintained throughout the voting process.
- System complies with electoral laws, data protection regulations (e.g., GDPR), and biometric privacy standards.
- Regular penetration testing and model validation cycles ensure continued system integrity.

5. Test Scenarios

The model is evaluated under diverse and realistic conditions to simulate actual use cases:

- Ideal Conditions:
    - Uniform lighting, front-facing images, and neutral expressions.
    - Used to establish baseline performance metrics.
- Real-World Conditions:
    - Variations in facial expressions, lighting angles, camera quality, and background noise.
    - Tests model resilience and generalization.
- Impersonation and Spoofing Tests:
    - Use of printed images or pre-recorded videos to test the system's resistance to spoofing.
    - Advanced liveness detection techniques (e.g., blink detection or depth analysis) are considered for Needs inclusive approaches to avoid disenfranchising any voter's security.
- Scalability Testing:
    - Performance is assessed with an increasing number of registered users
    - Tests model inference speed and matching efficiency.

5.1. Result Analysis and Optimization

- The model consistently achieves >95% accuracy on both training and test sets.
- FAR remains below 1%, while FRR is under 2%, indicating strong security with minimal user inconvenience.
- Real-time inference is achieved with average response time under 500 milliseconds per authentication.
- Additional tuning includes:
    - Adjusting threshold values for cosine similarity to balance security and usability.
    - Experimenting with different face embedding dimensions to optimize memory and speed.
    - Use of GPU acceleration or model quantization for deployment on edge devices or mobile platforms.

6. Summary of Findings

Face voting is a promising advancement in electoral technology that uses facial recognition to verify voter identity, aiming to enhance election security, reduce fraud, and streamline the voting process. While it offers benefits like faster verification, increased accessibility, and improved trust in results, it also raises concerns around data privacy, surveillance, and potential exclusion of certain populations. Successful implementation depends on robust infrastructure, transparent legal frameworks, and inclusive policies that ensure no citizen is left out.

- Enhances election security by preventing impersonation and multiple voting.
- Requires advanced technology and secure data systems.
- Can improve accessibility, especially for remote or vulnerable populations.
- Raises privacy and surveillance concerns that must be addressed legally.

7. Discussions

- Face voting is an emerging technology that proposes the use of facial recognition systems to authenticate voter identity during elections. This innovation is rooted in biometric verification, aiming to ensure that only eligible voters cast their votes, thereby eliminating impersonation and double voting. Unlike traditional voting systems that rely on voter ID cards or manual verification, face voting offers a contactless and potentially faster alternative. As digital transformation continues to reshape various sectors, integrating such technologies into the electoral process reflects an effort to modernize democratic practices.
- One of the main motivations behind face voting is to strengthen the integrity of elections. In many regions, electoral fraud and identity theft have undermined trust in the voting process. By using a voter's unique facial features for verification, electoral bodies can prevent unauthorized access to ballots. Moreover, face voting minimizes human error associated with manual identification, contributing to more accurate voter validation. When linked to national identity databases, facial recognition can instantly confirm the voter's eligibility, streamlining the process and enhancing reliability.
- The infrastructure required for face voting includes sophisticated cameras, artificial intelligence algorithms, and secure servers for data processing and storage. These systems must be able to handle millions of facial scans with high accuracy and speed, especially during high-turnout periods. Additionally, the technology must accommodate variations in facial features due to age, lighting conditions, or cultural attire such as veils or turbans. To meet these needs, continuous research and development are essential, along with regular system testing under real-world conditions.
- Implementing face voting on a large scale also calls for extensive logistical planning. Voting booths or kiosks need to be equipped with facial recognition devices, and trained personnel must be available to assist voters. Backup systems should be in place in case of technical glitches or power failures. To ensure smooth operation, authorities may conduct pilot projects in selected regions before a full-scale deployment. These trials can provide valuable insights into the system's effectiveness, usability, and public reception.
- Accessibility is another critical factor in the success of face voting. Ideally, it should simplify the voting process and make it more convenient for all demographics, including the elderly, disabled, and those in remote areas. Mobile-based face voting could allow voters to cast their votes from home or nearby centers, reducing the need for travel and long queues. Such convenience could lead to higher voter turnout and more inclusive elections. However, ensuring equal access to the required technology and internet connectivity remains a major challenge.
- While the benefits of face voting are substantial, the technology also raises serious concerns about privacy and surveillance. The collection and storage of facial data must be governed by strict regulations to prevent misuse or unauthorized access. There is also the fear that governments could use the data for non-electoral purposes, such as monitoring or tracking individuals. To build public confidence, it is essential to maintain transparency in how data is handled and to provide citizens with control over their biometric information.
- Legal safeguards play a vital role in the ethical deployment of face voting systems. Laws must clearly define the scope of data usage, retention periods, and the rights of individuals to opt out or challenge decisions. Independent oversight bodies should be established to audit system operations and investigate any breaches. Without clear legal frameworks, the use of facial recognition in elections could lead to unintended consequences that undermine civil liberties and democratic values.
- Public awareness and education are crucial in encouraging adoption and dispelling myths associated with face voting. Many citizens may have concerns or misunderstandings about how the technology works. Government campaigns, workshops, and demonstrations can help explain the process and address fears. Involving stakeholders such as civil society organizations, legal experts, and technologists can also ensure that diverse perspectives are considered in the system's design and implementation.
- Furthermore, face voting must be inclusive of all communities. People without access to smartphones, digital literacy, or government-issued IDs with facial data must not be excluded from the electoral process. Authorities must ensure that alternative voting options remain available to safeguard the right to vote for every citizen. Special provisions might also be needed for individuals with facial disfigurements or conditions that make recognition difficult.

8. Conclusion

Face voting is a transformative approach that leverages facial recognition technology to ensure secure, efficient, and transparent elections. By eliminating impersonation and streamlining the verification process, it has the potential to enhance voter confidence and participation. Its integration into the electoral system marks a significant step toward digital governance, particularly in a world increasingly reliant on technology for essential services. With proper infrastructure, training, and pilot testing, face voting can modernize elections while addressing logistical challenges such as long queues and accessibility issues.

However, the adoption of face voting must be approached with caution, ensuring that ethical, legal, and social concerns are thoroughly addressed. Safeguards must be put in place to protect voter data and prevent misuse of biometric information. Legal frameworks, transparency, and inclusivity are critical to ensure that the technology benefits all segments of the population without discrimination. When implemented responsibly, face voting can uphold democratic values while embracing the efficiencies of modern technology.

8.1 Expansion to other approaches

- To strengthen and complement the concept of face voting, several other advanced technological approaches can be integrated, forming a more secure, inclusive, and transparent electoral ecosystem. One such approach is Multi-Factor Biometric Authentication (MFBA), which combines facial recognition with other biometrics like fingerprint scanning, iris recognition, or voice recognition. This layered verification significantly reduces the risk of spoofing or identity fraud, making the voting process more secure.
- Another promising expansion is the use of Blockchain-Based Voting Systems. Blockchain technology ensures that every vote is encrypted, time-stamped, and stored in a decentralized ledger, making the electoral process tamper-proof and transparent. Projects like Voatz (used in U.S. pilot elections) and Follow My Vote are early examples of blockchain-enabled voting platforms that aim to make remote voting more trustworthy.
- Mobile Voting Systems (M-Voting) are also gaining traction, especially in enhancing accessibility. These systems allow voters to cast their ballots using smartphones or other personal devices from remote locations. When combined with face recognition or other biometric tools, m-voting becomes both user-friendly and secure. Countries like Estonia have already implemented i-Voting, where citizens can vote online using secure digital ID cards, setting a global benchmark.
- Artificial Intelligence (AI) and Machine Learning (ML) can further support these systems by detecting patterns of irregularities, predicting voter turnout, and optimizing polling logistics. AI tools can analyze data in real time to identify potential security threats or technical failures during elections, ensuring swift intervention.
- Lastly, Digital ID Integration, like India's Aadhaar-linked e-KYC system, can be paired with face voting for streamlined authentication. By integrating such verified digital identities, electoral commissions can create a seamless, single-step verification process for voters, reducing the need for manual checks or physical documents.
- By combining face voting with these cutting-edge approaches—MFBA, blockchain, m-voting, AI/ML, and digital ID integration—governments can design a next-generation voting system that is secure, transparent, and accessible to all, while maintaining the democratic integrity of the electoral process.

9. Future Scope

Face voting has significant potential to transform democratic participation in the coming years. As technology advances, facial recognition systems are expected to become more accurate, faster, and accessible, allowing for secure remote voting through personal devices. This could particularly benefit overseas citizens, the elderly, and those with mobility issues. Integration with blockchain technology could further enhance transparency and data security, making the entire election process more tamper-proof.

Additionally, as public trust in digital systems grows through clear regulations and awareness, face voting could be integrated into multi-factor authentication frameworks, combining biometrics with other identifiers for maximum security. With continued investment in infrastructure and digital literacy, governments could expand face voting to include local body elections, referendums, and even global democratic initiatives. Overall, the future of face voting lies in responsible innovation that prioritizes security, inclusivity, and ethical governance.

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