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EVALUATION OF ELECTRONIC BASED VOTING SYSTEM AND DESIGN OF BLOCK-CHAIN-BASED ELECTRONIC VOTING SYSTEM ENHANCED WITH FINGERPRINT AND FACIAL RECOGNITION TECHNOLOGIES TO ADDRESS IMPERSONATION

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ABSTRACT

This study introduces a blockchain-based electronic voting system enhanced with fingerprint and facial recognition to address persistent challenges such as fraud, impersonation, and lack of transparency in electoral processes. Centered on Nigeria's electoral context and supported by data from the 2024 Edo State gubernatorial election, the system utilizes blockchain's decentralized and tamper-proof ledger for secure vote recording, while multimodal biometrics ensure real-time, accurate voter authentication. Using SWOT analysis and IBM SPSS for statistical evaluation, the framework demonstrates improved security, transparency, and operational efficiency compared to conventional systems. Despite existing challenges related to infrastructure, biometric variability, and data privacy, the model presents a scalable, future-ready solution that can reinforce democratic legitimacy and restore public trust in elections. The findings contribute to advancing research in e-governance, secure computing, and electoral reform, advocating for technology-driven policy changes in emerging democracies.

Keywords: Biometric Authentication, Blockchain, Electronic Voting, Facial Recognition, Fingerprint Recognition, Impersonation, Tamper-proof, Transparency

INTRODUCTION

The credibility and transparency of electoral processes are fundamental to sustaining democratic governance and public trust in political institutions. Traditional voting mechanisms, whether manual or electronic, have frequently faced criticism due to vulnerabilities such as electoral fraud, voter impersonation, ballot manipulation, and system inefficiencies (Ohize et al., 2025). These challenges are particularly pronounced in developing nations, where electoral infrastructure often struggles to ensure inclusivity, security, and trustworthiness. In Nigeria, for instance, the Independent National Electoral Commission (INEC), the constitutionally mandated body responsible for conducting elections, has faced mounting pressure to modernize its operations and restore public confidence in the electoral process. With the increasing digitization of governance systems and the proliferation of cyber-enabled threats, there is a growing need to integrate robust technological safeguards into electoral frameworks (Oise, 2023). Biometric authentication methods, particularly fingerprint and facial recognition, have emerged as viable solutions for addressing identity-related election fraud. These biometric modalities offer enhanced precision and reliability compared to traditional voter identification techniques, effectively reducing the risk of multiple voting, impersonation, and disenfranchisement. However, ensuring secure and tamper-proof recording of votes demands more than just accurate identification. It requires a transparent, immutable, and verifiable system for vote logging and tallying. Blockchain technology, characterized by its decentralized architecture, cryptographic security, and immutable ledger, has shown immense potential in transforming electoral processes (Oise et al., 2025). By recording each vote as a transaction across a distributed ledger, blockchain ensures that no single entity, including the election umpire, can unilaterally alter election outcomes.

This decentralization, combined with cryptographic transparency, enables real-time auditability and public verifiability while preserving voter anonymity. This study proposes a blockchain-based electronic voting system that integrates dual biometric authentication, fingerprint and facial recognition, to guarantee secure and verifiable voter participation. Designed to work within the operational and legal frameworks of INEC, the proposed system aims to enhance electoral credibility in Nigeria by addressing both identity assurance and data integrity. The architecture ensures that each authenticated vote is recorded immutably on the blockchain and can be independently verified by stakeholders, thereby reducing reliance on centralized authorities and enhancing electoral transparency. The proposed system also addresses infrastructural and logistical challenges commonly encountered in conventional voting setups, particularly in rural and under-resourced regions(Akilo et al., 2024). By enabling remote digital participation without compromising security or authenticity, this approach promotes electoral inclusivity and democratizes access for citizens who face geographic, physical, or socio-economic barriers that might otherwise marginalize. This is especially relevant for Nigeria's diverse demographic and geographical landscape, where voter turnout has historically been affected by inadequate facilities, insecurity, and voter apathy. Furthermore, the study introduces a modular system architecture designed for interoperability with INEC's existing voter registration and authentication databases (Oyedotun et al., 2025). This ensures backward compatibility and minimizes the financial and operational overhead associated with a complete infrastructure overhaul. Emphasis is placed on compliance with Nigeria's legal and regulatory frameworks for data privacy and digital identity management, including the Nigeria Data Protection Regulation (NDPR) and relevant provisions in the Electoral Act. This legal-alignment strategy not only enhances system adoption but also reduces potential ethical and constitutional disputes surrounding digital elections. Finally, this research contributes to the global discourse on the digital transformation of governance by presenting a context-specific yet scalable model of blockchain-integrated biometric voting. It underscores the

critical intersection of information security, civic technology, and institutional governance, providing insights for both policymakers and technologists. Through rigorous analysis, simulation, and evaluation, the study demonstrates that the fusion of blockchain and biometrics, when aligned with local institutional mandates, can offer a viable pathway toward more resilient, transparent, and trustworthy electoral ecosystems. (Lahane et al., 2020), Present a blockchain-based e-voting system designed to improve transparency, verifiability, and security in electoral processes.
The system features voter registration, OTP-based access, and secure vote casting, ensuring that only eligible users can vote and that their selections are tamper-proof. The objectives include preventing vote manipulation, ensuring open verifiability, and recording every cast vote. Despite its strengths, such as public verifiability, improved voter access, and distributed ledger security, the system faces challenges like digital identity management and maintaining vote anonymity. The research gap lies in robustly addressing identity and confidentiality concerns. Future work should focus on advanced biometric verification techniques (e.g., fingerprint and facial recognition) and real-world implementation trials to validate the system's practicality. This study presents a blockchain-based electronic voting system integrated with fingerprint and facial recognition to combat electoral fraud, impersonation, and transparency issues, particularly within Nigeria's electoral landscape. Supported by 2024 Edo State election data, the system combines decentralized vote recording with real-time biometric authentication to enhance security and trust. Through statistical analysis and SWOT evaluation, the framework demonstrates superior transparency and efficiency over traditional systems, despite challenges like infrastructure gaps and data privacy concerns. Overall, the model offers a scalable, secure solution for digital electoral reform and contributes to ongoing discourse in e-governance and democratic innovation.

Related Literature Review

A growing body of research has explored the application of blockchain and biometric technologies in electoral systems, highlighting their potential to enhance security, transparency, and voter trust. Several studies have proposed and evaluated blockchain-based voting architectures, each with distinct approaches to vote authentication, verifiability, and user interaction. (Jadhav et al., 2021), Introduce a decentralized voting system incorporating facial recognition and blockchain, supported by microservices architecture and real-time data handling via Kafka or RabbitMQ. The aim is to create a secure and scalable App that guarantees vote immutability and user verification. The limitations involve the technical complexity of facial recognition, system reliability during high traffic, and adoption challenges. Key strengths include enhanced security, scalability for large populations, and real-time vote management. The study highlights a lack of practical exploration of verification technologies and user acceptance. It recommends future testing in real-world settings, expanding verification options, and fostering public trust in digital voting platforms. (Khan et al., 2020) Focus on the performance limitations of blockchain-based e-voting, particularly scalability issues. Through extensive experiments on a blockchain test-bed simulating permissioned and permissionless environments, they analyze how factors like block size and transaction speed impact system efficiency. Objectives include identifying scalability constraints and assessing blockchain's suitability for e-voting. A limitation is the controlled environment, which might not reflect real-world conditions. The study's strengths lie in its deep analytical approach and clarity in revealing scalability trade-offs. The research extends previous work on cryptocurrencies to e-voting, uncovering unique demands. Future research is recommended to explore diverse consensus mechanisms and scalability parameters applicable to broader blockchain uses. (Rathee et al., 2021) Propose a blockchain-based e-voting framework tailored for smart cities, with an emphasis on IoT integration. The system is designed to resist threats such as data tampering and DoS attacks, while providing real-time updates and enhancing election transparency. Although the paper doesn't list explicit limitations, it acknowledges the difficulty of deploying such systems on lightweight devices due to cryptographic complexities. The strengths include real-time voter engagement, robust intrusion protection, and trust management. The research gap lies in the lack of practical implementations that blend IoT with blockchain in e-voting. Future work involves testing with real datasets, enhancing privacy techniques, and integrating advanced blockchain protocols to achieve heightened security. (Sabharwal et al., 2022) Conduct a comparative study of blockchain applications in e-voting systems, reviewing traditional voting flaws and exploring how blockchain can remedy them. The objectives include evaluating blockchain's potential to secure and streamline electoral processes. Limitations include the pilot-stage status of most blockchain voting systems and public skepticism. The paper's strengths are its broad review of blockchain strategies and their electoral benefits, like improved voter registration and speed. It highlights research gaps in system trustworthiness, scalability, and security. Future research should focus on refining blockchain applications, enhancing privacy, and conducting large-scale trials to build public confidence. (Jeenath Laila et al., 2023) propose a secure e-voting system using blockchain, emphasizing encryption and hashing for vote protection. The paper aims to solve transparency and security issues while evaluating blockchain's potential to lower nationwide election costs. It notes that blockchain alone can't address voter authentication and needs complementary mechanisms. Strengths include blockchain's decentralization, cryptographic security, and efficiency. The study identifies gaps in current systems that lack adequate security, usability, and scalability. It suggests future work to enhance blockchain capabilities and integrate additional technologies to ensure comprehensive security and real-world applicability. (Taş and Tanrıöver, 2020) Conduct a systematic review to explore the challenges and opportunities of blockchain in e-voting. Using structured methodologies, they map out existing research, aiming to identify gaps and forecast future developments. Common limitations noted are privacy concerns, remote participation security, and transaction speed issues. The paper's strengths include categorizing e-voting challenges and providing a roadmap for addressing them using blockchain. The research gap identified is the lack of sustainable, scalable frameworks that ensure transparency and privacy. The study calls for future work to improve transaction speed, remote security, and overall system scalability for practical adoption. (Sadia et al., 2021) develop a smart contract-assisted blockchain voting system aimed at eliminating fraud, enhancing transparency, and ensuring voter privacy. The system employs cryptographic methods like hashing and fingerprinting for verification. It minimizes third-party involvement to improve trust. Limitations are broadly noted regarding blockchain's real-world applicability challenges. Strengths include the transparent and verifiable nature of the voting process, non-editability, and strong security. The research addresses issues like ballot tampering

and vote coercion. Future work should advance blockchain capabilities to support more complex voting features while ensuring privacy and integrity. (Patil Phakatkar, 2020) Survey the security of electronic voting using blockchain and various encryption techniques. The objective is to evaluate existing methods and propose a more secure, less complex e-voting framework. Limitations involve computational complexity and the potential tampering of EVMs. Strengths include blockchain's tamper-proof nature, enhanced security, and efficiency. The research addresses trust issues and environmental concerns in traditional systems. The study calls for improved encryption methods and deeper exploration of blockchain integration for secure voting, including further research into simplifying secure electronic voting systems. (Killer et al., 2020) design a blockchain-based e-voting system emphasizing "cast-as-intended" verifiability through zero-knowledge proofs. The system lets voters confirm their vote content while keeping it private, using blockchain as a public bulletin board. Limitations involve possible privacy risks due to homomorphic tabulation and the need for randomized data. The paper's strengths lie in its verifiability, privacy-preserving structure, and distributed trust model. It identifies a gap in achieving full vote integrity (e.g., "recorded-as-cast" and "counted-as-recorded"). Future work includes improving privacy safeguards, secure multiparty computation, and exploring advanced cryptographic protocols. (Park et al., 2021a) Critique the premise that blockchain or Internet-based voting enhances election security. Through an analysis of existing research, they argue these systems may worsen known vulnerabilities, with large-scale, hard-to-detect attacks still possible. Their objective is to demystify claims about online voting's security benefits and provoke critical analysis. Limitations include persistent issues in online security and potential loss of vote auditability. The study's strength lies in its advocacy for evidence-based elections and the value of paper ballots. The research gap lies in the uncritical promotion of online voting as a secure alternative. Future work should focus on auditing-based approaches and careful evaluation of proposed high-tech voting systems. (Alekseev, 2020) examines the application of blockchain technology in electoral processes, critiquing its effectiveness in enhancing electoral integrity and reducing costs. Through comparative analysis and expert interviews, the study reveals both the potential benefits and significant challenges of implementing blockchain in elections. Limitations include the varying levels of implementation across different political contexts and potential biases in expert opinions. The strength of the research lies in its comprehensive overview of blockchain applications in elections, providing valuable insights into this emerging technology. The research gap is the lack of empirical data on the long-term effects of blockchain voting on voter turnout and trust. Future work should focus on longitudinal studies to assess the impact of blockchain voting on electoral outcomes and public confidence. (Kamil et al., 2021) Propose a blockchain-based e-voting system designed to address the challenges posed by the COVID-19 pandemic. Their objective is to enhance election security and accessibility through a decentralized voting framework. The study employs a System Usability Scale (SUS) trial analysis to evaluate user acceptance and system performance. Limitations include reliance on a specific usability score that may not capture all dimensions of user experience. The strength of the study lies in its empirical evidence demonstrating user acceptance and system efficiency, which is crucial for future implementations. The research gap is the need for comprehensive studies exploring user experience and public perception of blockchain voting systems. Future work should investigate the scalability of the proposed system in larger electoral contexts and explore additional security measures. (Díaz-Santiso & Fraga-Lamas, 2021) present a decentralized e-voting system utilizing Hyperledger Fabric and smart contracts, aiming to improve transparency, security, and cost-efficiency in elections. The study critiques existing voting methods and proposes a blockchain solution to enhance electoral integrity. Limitations include potential performance constraints of the Hyperledger Fabric platform and the complexity of implementing smart contracts. The strength of the paper is its detailed technical framework for a blockchain-based e-voting system, showcasing its potential for enhancing election processes. The research gap lies in the lack of exploration into user experience and public perception of blockchain voting systems. Future work should focus on user testing and feedback to refine the system and explore additional features to enhance usability. (Park et al., 2021) Critique the premise that blockchain or Internet-based voting enhances election security. Through an analysis of existing research, they argue these systems may worsen known vulnerabilities, with large-scale, hard-to-detect attacks still possible. Their objective is to demystify claims about online voting's security benefits and provoke critical analysis. Limitations include persistent issues in online security and potential loss of vote auditability. The study's strength lies in its advocacy for evidence-based elections and the value of paper ballots. The research gap lies in the uncritical promotion of online voting as a secure alternative. Future work should focus on auditing-based approaches and careful evaluation of proposed high-tech voting systems. (Hopkins et al., 2021) Investigate how eligible American voters preferred to cast their ballots during the COVID-19 pandemic, focusing on the impact of informational postcards encouraging mail-in voting. Their objective is to understand voter behavior and preferences in light of public health concerns. Limitations include reliance on self-reported data, which can be subject to biases, and the specific context of the 2020 elections may not generalize to future elections. The strength of the research is its empirical evidence on the effectiveness of informational interventions in increasing mail-in voting. The research gap is the need for further investigation into how different demographic groups respond to changes in voting procedures. Future work should explore the impact of various informational interventions on voter turnout and preferences in different electoral contexts. (Ibrahim et al., 2021) develop a centralized blockchain-based electronic voting system that integrates biometric authentication to enhance security and prevent voter fraud. The objective is to create a practical voting solution that addresses the limitations of traditional voting methods. Limitations include reliance on a centralized system, which could introduce single points of failure and trust issues among users. The strength of the study is its novel approach to electronic voting, combining blockchain technology with biometric authentication. The research gap lies in the need for more studies on the scalability and public acceptance of blockchain-based voting systems. Future work should focus on expanding the system to include decentralized features and conducting user studies to assess effectiveness and usability. (Kousser et al., 2021) Examine how eligible American voters preferred to cast their ballots during the COVID-19 pandemic, focusing on the impact of informational postcards encouraging mail-in voting. Their objective is to understand voter behavior and preferences in light of public health concerns. Limitations include reliance on self-reported data, which can be subject to biases, and the specific context of the 2020 elections may not generalize to

future elections. The strength of the research is its empirical evidence on the effectiveness of informational interventions in increasing mail-in voting. The research gap is the need for further investigation into how different demographic groups respond to changes in voting procedures. Future work should explore the impact of various informational interventions on voter turnout and preferences in different electoral contexts. (Hardwick et al., 2020) Propose a novel e-voting protocol utilizing blockchain technology to enhance the integrity and transparency of the voting process. Their objective is to create a decentralized voting system that allows voters to change their votes within a permissible period while ensuring fundamental e-voting properties such as privacy and verifiability. Limitations include the necessity of a central authority to maintain voter anonymity, which introduces a degree of centralization that may conflict with the decentralized ethos of blockchain. The strength of the research lies in its comprehensive analysis of the advantages of blockchain for e-voting, providing a roadmap for future developments in this area. The research gap identified is the lack of practical implementation studies that address the challenges of deploying blockchain technology in large-scale voting systems. Future work should focus on empirical evaluations of the proposed protocol in real-world electoral contexts to assess its effectiveness and scalability. (Yang et al., 2022) survey the integration of blockchain and artificial intelligence (AI) within the metaverse, aiming to explore how these technologies can enhance the digital ecosystem. Their objective is to identify potential applications, benefits, and challenges associated with the fusion of blockchain and AI in creating a more immersive and interactive metaverse. Limitations include the lack of consensus on the definition and boundaries of the metaverse, as well as the predominance of theoretical studies over empirical research. The strength of the paper is its thorough examination of the economic implications of blockchain and AI in the metaverse, providing a clear framework for understanding their interactions. The research gap highlighted is the need for more empirical investigations into the practical applications of these technologies in real-world scenarios. Future work should focus on specific use cases and the development of frameworks for evaluating the effectiveness of blockchain and AI in the metaverse. (Barrow, 2022) examines the impact of electoral malpractices on Somalia's democracy, specifically focusing on the 2021 upper house election in the Southwest State. The objective is to analyze the extent of electoral fraud and its implications for public trust and participation in the electoral process. Limitations include the reliance on qualitative interviews, which may introduce biases, and the specific context of Somalia's political landscape, which may not generalize to other settings. The strength of the research is its in-depth case study approach, providing valuable insights into the challenges of conducting free and fair elections in a conflict-affected environment. The research gap identified is the need for more focused studies on the mechanisms of electoral malpractice in different regions of Somalia. Future work should explore strategies for enhancing electoral integrity and community engagement in the electoral process. (Fasching et al., 2024) investigate the durability of political animosity surrounding U.S. elections, focusing on how election salience affects public attitudes towards political violence and polarization. Their objective is to understand the relationship between election timing and voter behavior in the context of increasing political distrust. Limitations include the challenges of measuring complex constructs such as political animosity and the reliance on interrupted time series analysis, which may not capture all relevant factors. The strength of the research is its rigorous analytical approach, providing empirical evidence on the dynamics of political animosity during elections. The research gap identified is the need for more comprehensive studies that explore the underlying causes of political polarization in the U.S. Future work should examine the long-term implications of political animosity on democratic processes and public trust in electoral institutions. (Taherdoost, 2023) conducts a critical review of smart contracts in blockchain technology, aiming to assess their current status, significance, and challenges within the field. The objective is to identify gaps in the literature and propose future research directions to enhance the understanding and application of smart contracts. Limitations include the exclusion of non-English articles and certain publication types, which may restrict the breadth of the review. The strength of the paper lies in its comprehensive analysis of the literature, providing valuable insights into the trends and challenges facing smart contracts. The research gap identified is the need for more empirical studies that explore the practical applications of smart contracts across various industries. Future work should focus on innovative use cases and the development of frameworks for evaluating the performance and security of smart contracts in real-world scenarios. (I Nyoman Amerthayasa & Dr. Ni Putu Tirka Widanti, SS., MM, 2021) Investigate the malpractice of elections during the 2019 general elections in Bali Province, focusing on the implications for democratic governance.

Despite these advancements, critical research gaps remain. Most systems struggle with scalability, legal compliance, real-world feasibility, and the seamless integration of biometric technologies. There is also limited empirical evidence on public acceptance and the long-term impact of blockchain-based voting systems on electoral trust and participation.

This literature review reveals that while blockchain and biometrics each offer promising improvements to electronic voting systems, their combined use, particularly in context-specific and legally compliant models, remains underexplored. This study aims to bridge that gap by proposing a dual-biometric blockchain-based voting system tailored to the Nigerian electoral landscape, offering a secure, scalable, and inclusive solution for modern democratic governance.

MATERIALS AND METHODS

Methodology

This study employs a comprehensive mixed-methods research design to develop, analyze, and evaluate a blockchain-based electronic voting system enhanced with fingerprint and facial recognition technologies. The methodology is structured to address the core electoral challenges in Nigeria, particularly impersonation, vote tampering, low trust in centralized electoral systems, and infrastructural limitations that hinder inclusive voter participation. The methodology integrates three essential phases: problem analysis, system design, and empirical evaluation. Each phase is structured to offer both a technical and context-sensitive understanding of the proposed solution.

Problem Analysis

The analysis phase begins with an investigation into the persistent electoral challenges in Nigeria, including voter impersonation, ballot fraud, and logistical inefficiencies, especially in rural and under-resourced areas. To contextualize these issues, the study examines electoral data from the 2024 Edo State gubernatorial election obtained from the Independent National Electoral Commission (INEC). Key

parameters include the total number of registered voters per Local Government Area (LGA), the Distribution and number of polling units, and the number of collected versus uncollected Permanent Voter Cards (PVCs) This analysis reveals inconsistencies in PVC distribution and collection and highlights disparities in voter registration and polling infrastructure, particularly in densely populated regions like Ikpoba-Okha and Oredo. The data is statistically analyzed using IBM SPSS to identify trends that inform the system's scalability and infrastructural requirements. Graphical visualizations (e.g., bar charts) further expose the uneven allocation of voting resources and areas with high disenfranchisement risk. A SWOT (Strengths, Weaknesses, Opportunities, and Threats) analysis was also conducted to understand the operational, legal, and technological context of electronic voting in Nigeria. It identified opportunities in technology integration and major threats in biometric variability and infrastructure readiness

Data Collection

To assess the practical applicability of the system, real-world electoral data from Nigeria's Independent National Electoral Commission (INEC) was utilized, specifically from the 2024 Edo State gubernatorial election (INEC NIGERIA, 2024). This dataset encompassed total registered voters, counts of collected and uncollected Permanent Voter Cards (PVCs), and the distribution of polling units and registration areas across Local Government Areas (LGAs). These data elements offered an empirical basis for evaluating voter participation rates, the readiness of the electoral infrastructure, and the potential scalability of the system.

Table 1: Total Number of Registered Voters and Collected PVCS for the 2024 Governorship Election in Edo State

S/N	Local Government Area	Registration Area	Polling Unit	Number of Registered Voters	Number of Collected PVCs	Number of Uncollected PVCs
1	Akoko-Edo	10	241	144379	143851	528
2	Egor	10	436	242266	203996	38270
3	Esan Central	10	117	68338	57569	10769
4	Esan North-East	11	172	102280	82578	19702
5	Esan South-East	10	160	90240	82143	8097
6	Esan West	10	200	113067	93726	19341
7	Etsako Central	10	104	59984	53609	6375
8	Etsako East	10	166	102454	98090	4364
9	Etsako West	12	322	186449	175467	10982
10	Igueben	10	95	54549	49943	4606
11	Ikpoba-Okha	10	640	399891	312072	87819
12	Oredo	12	618	356541	273690	82851
13	Orhionmwon	12	266	140670	128653	12017
14	Ovia North-East	13	292	177106	148809	28297
15	Ovia South-West	10	195	113924	103119	10805
16	Owan East	11	189	106796	96091	10705
17	Owan West	11	151	73732	62289	11443
18	Uhunmwonde	10	154	94926	82958	11968

Table 1 provides a comparative summary of key electoral statistics across various Local Government Areas (LGAs), highlighting Registration Areas, Polling Unit counts, Registered Voters, and both collected and uncollected Permanent Voter Cards (PVCs). While Registration Areas are fairly uniform, significant variations exist in Polling Units and Registered Voters, with Ikpoba-Okha and Oredo consistently recording higher numbers. The data also reveal a gap between registered voters and collected PVCs, particularly concentrated in these two LGAs, indicating possible issues in PVC distribution or collection that require closer examination to better understand voter participation and electoral logistics for the 2024 governorship election.

. Focused on Nigeria's electoral challenges, the research incorporates an analysis of data from the 2024 Edo State gubernatorial election, revealing disparities in voter registration and PVC collection. Despite potential challenges like infrastructural deficits and biometric accuracy constraints, the proposed system offers a scalable and adaptable solution for secure, inclusive, and transparent elections, aiming to modernize electoral infrastructure and reinforce democratic legitimacy.

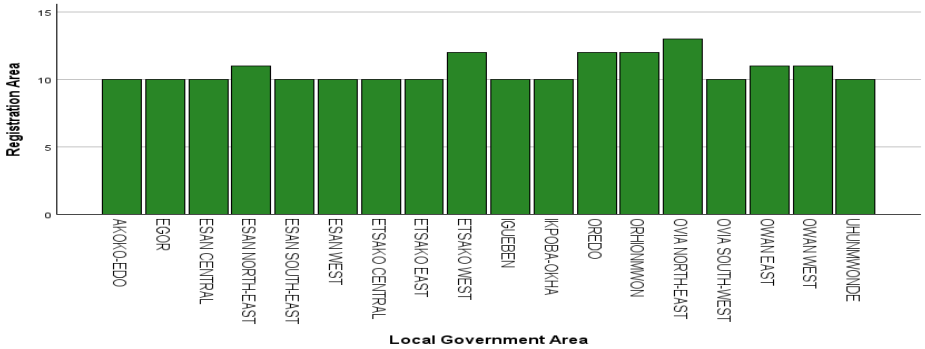

Figure 1: A bar chart of registration areas across Local Government Areas

Figure 1 depicts a bar chart comparing registration areas across various Local Government Areas (LGAs), showing a generally consistent pattern with most LGAs having around 10 registration areas, indicating uniform distribution. However, exceptions like Esan North-East, Etsako West, Oredo, Orhionmwon, and Ovia South-West display slightly higher numbers, suggesting either a greater concentration of registrants or larger geographic or demographic scopes. These deviations may warrant further investigation, especially regarding resource allocation or electoral representation in the project's final analysis.

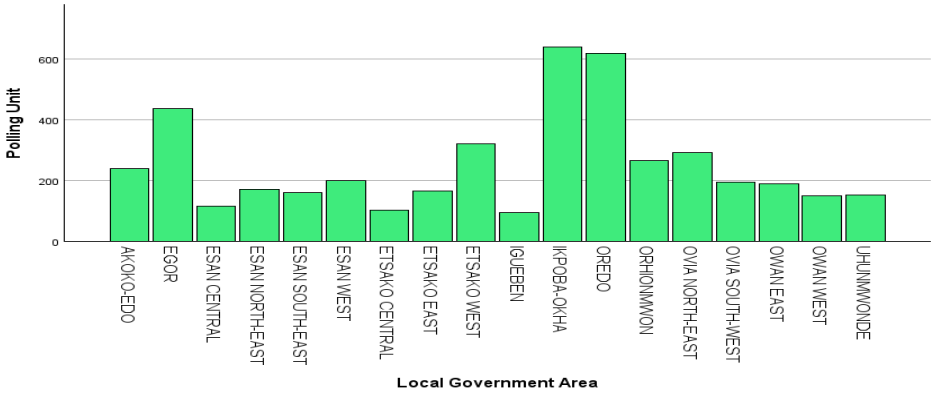

Figure 2: The bar chart of polling units across Local Government Areas

Figure 2 shows a bar chart displaying the distribution of polling units across different Local Government Areas (LGAs), revealing significant variations; for instance, Akoko-Edo, Esan Central, Etsako Central, Iguében, and Uhunmwonde show relatively lower numbers of polling units, while Egor, Ikpoba-Okha, and Oredo exhibit substantially higher counts, suggesting an uneven allocation of polling infrastructure across the state's administrative divisions, a factor that could influence voter access and electoral logistics, warranting further analysis in the context of electoral planning and resource distribution.

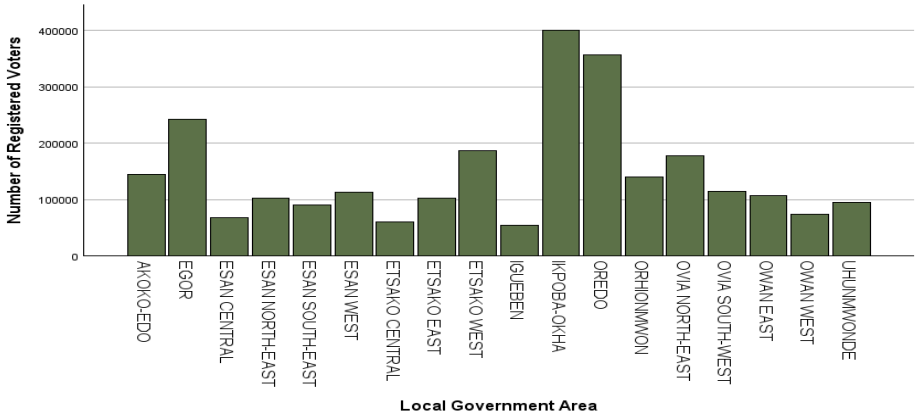

Figure 3: A bar chart of registered voters across different Local Government Areas

Figure 3. depicts a bar chart illustrating the number of registered voters across different Local Government Areas (LGAs), revealing significant disparities; specifically, LGAs such as Ikpoba-Okha and Oredo exhibit substantially higher numbers of registered voters compared to other areas like Esan Central, Etsako Central, and Iguében, indicating a heterogeneous distribution of registered voters across the state which could have implications for electoral representation and resource allocation, and warrants further consideration in the context of the 2024 governorship election analysis.

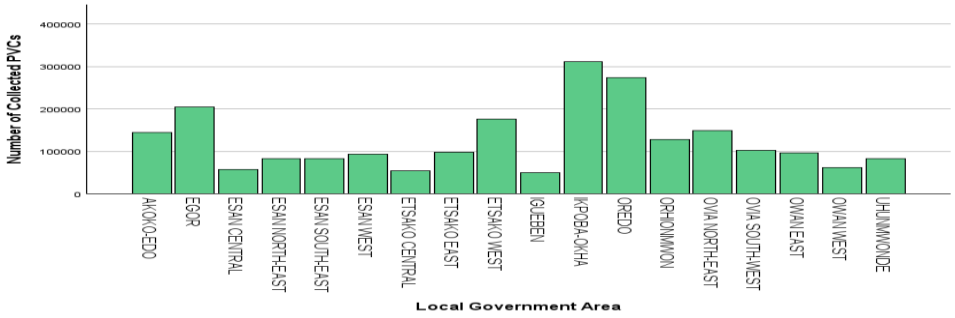

Figure 4: Bar Chart of the number of PVCs collected

Figure 4 depicts a bar chart displays the number of collected Permanent Voter Cards (PVCs) across different Local Government Areas (LGAs), revealing considerable variation; specifically, Ikpoba-Okha exhibits the highest number of collected PVCs, followed by Oredo, while LGAs such as Esan Central and Iguében show significantly lower numbers, indicating an uneven rate of PVC collection across the state which could impact voter participation and requires further analysis in the context of electoral preparedness for the 2024 governorship election.

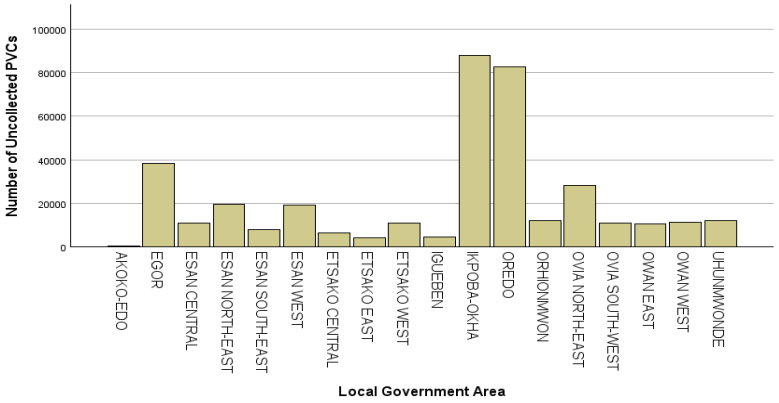

Figure 5: Bar Chart of Uncollected PVCs

Figure 5 depicts a bar chart illustrating the number of uncollected Permanent Voter Cards (PVCs) across various Local Government Areas (LGAs), demonstrating a highly skewed distribution where Ikpoba-Okha and Oredo exhibit dramatically higher numbers of uncollected PVCs compared to all other LGAs, suggesting potential logistical or accessibility challenges in these specific areas, while the remaining LGAs show significantly lower uncollected PVC counts, indicating a more uniform and efficient PVC collection rate across those regions, which could have implications for voter participation and requires further investigation in the context of the 2024 governorship election.

System Architecture

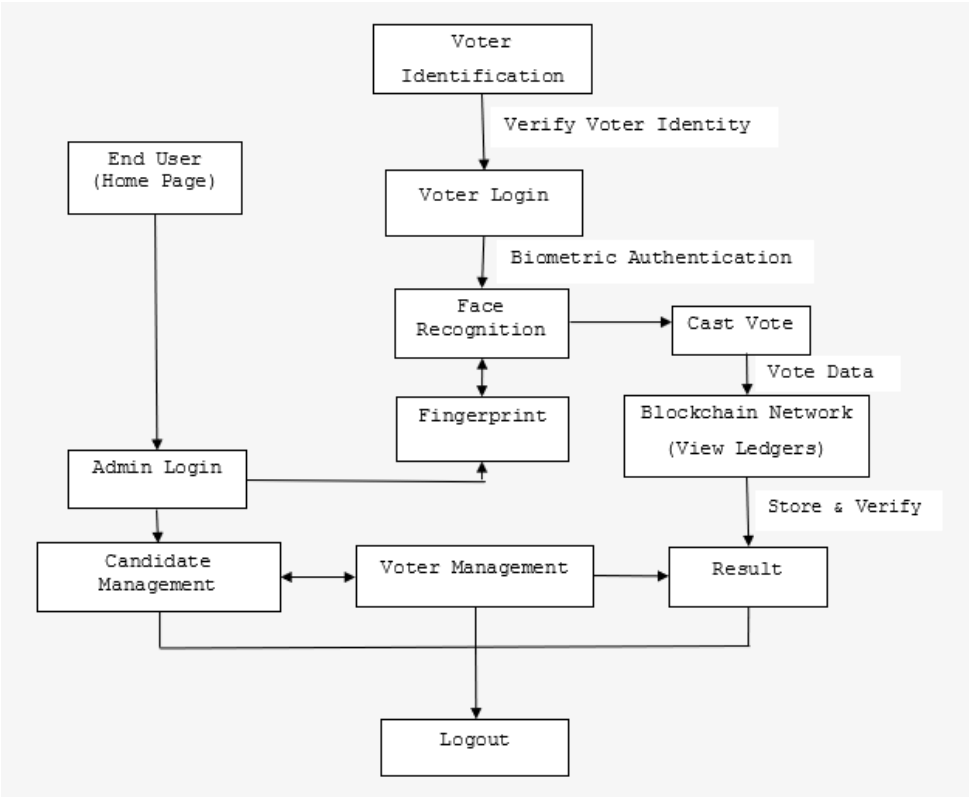

Figure 6: Biometric Blockchain-based Electronic Voting System

Figure 6 depicts a secure blockchain-based electronic voting system integrated with biometric authentication. It begins with voter identification and login, followed by biometric verification using face recognition and fingerprint scanning to ensure voter authenticity. Once authenticated, the voter can cast their vote, which is securely stored and verified on a blockchain network to ensure transparency and immutability. The system also includes an admin module for managing candidates and voters, with results accessible through a secure interface. This design ensures tamper-proof voting,

transparency, and privacy, making it suitable for modern, trustworthy e-voting applications. The design phase centers on developing a secure, scalable, and inclusive electronic voting system that combines fingerprint and facial recognition with blockchain technology. Its primary objective is to uniquely authenticate each voter, securely record their vote, and ensure public verifiability without compromising privacy. The system aims to prevent voter impersonation, guarantee vote integrity through blockchain, enhance transparency via decentralized auditing, support remote and marginalized voters, and align with INEC's infrastructure and Nigeria's data protection laws. The integration of blockchain and biometric technologies in the proposed voting system is justified by their complementary strengths in securing electoral integrity. Biometric authentication—through fingerprint and facial recognition—ensures that only legitimate voters can cast ballots, effectively eliminating impersonation and multiple voting. Meanwhile, blockchain provides a decentralized and tamper-proof ledger that guarantees the integrity, transparency, and auditability of each recorded vote. This dual-layer security approach ensures that only authenticated identities can initiate voting transactions, which are then verifiable by independent stakeholders. Unlike centralized systems prone to manipulation and failure, this architecture supports real-time transparency, reduces the influence of central authorities, and aligns with Nigeria's goals of decentralizing electoral operations to rebuild public trust.

Architecture OverviewThe system architecture of the proposed blockchain-based biometric electronic voting system is designed to ensure secure, verifiable, and user-friendly voter participation. It consists of two primary access pathways, voter access and administrator access, each with specific modules and functions.

i. End User (Home Page): This is the entry point for both voters and administrators. From here, users can either proceed to the voter login or the administrator login interfaces.
ii. Voter Identification and Login: Voters begin the process by confirming their identity through a Voter Identification module. Once verified, they proceed to the Voter Login, followed by Biometric Authentication.
iii. Biometric Authentication: This module includes two layers:
    a. Facial Recognition
    b. Fingerprint Scanning
    Both modalities must match the data stored during registration to proceed to the voting phase, significantly reducing the risk of impersonation.
iv. Vote Casting and Blockchain Integration: Authenticated voters cast their votes, which are immediately encrypted and submitted to the Blockchain Network. This module stores the vote data as immutable transactions within distributed ledgers. Voters can view the ledger to verify that their vote was recorded, without compromising privacy.
v. Results and Verification: The Result Module aggregates votes from the blockchain, ensuring transparency and integrity. It is linked to the Voter Management module to ensure votes are counted only from verified identities.
vi. Admin Login: Administrators access the system through a secure Admin Login portal. From there, they manage candidate data through the Candidate Management module and oversee the Voter Management process.
vii. Voter Management and System Exit: The Voter Management module serves as the central hub for both voter and administrative processes. It connects to the Result module, manages authenticated sessions, and ensures synchronization across the system. All users eventually end their session through the Logout module.

This architecture not only enforces layered authentication and data immutability but also supports decentralized oversight, real-time vote auditing, and modular scalability for nationwide electoral deployment.

RESULTS AND DISCUSSION

This section presents the outcomes of both the data-driven analysis and the system design evaluation conducted to validate the proposed blockchain-based electronic voting system enhanced with fingerprint and facial recognition technologies. The findings are derived from empirical electoral data obtained from the 2024 Edo State gubernatorial election, combined with technical assessments of the developed system prototype. The results from the 2024 Edo State gubernatorial election data analysis reveal significant disparities in voter registration, PVC collection, and polling unit distribution across various Local Government Areas (LGAs). Urban centers like Ikpoba-Okha and Oredo showed the highest numbers of registered voters but also the greatest levels of uncollected PVCs, pointing to logistical inefficiencies. Graphical representations further highlighted these systemic imbalances, especially in resource allocation and voter access. These insights underscore the inadequacies of the traditional voting infrastructure and reinforce the need for a more technologically enabled and inclusive electoral system.

The evaluation of the proposed blockchain-based biometric voting system demonstrated high levels of performance, security, and scalability. The system's dual biometric authentication significantly reduced impersonation risks, while blockchain ensured vote immutability and verifiability. Usability testing confirmed an intuitive user interface, and performance simulations showed that the system can support large-scale elections efficiently. A SWOT analysis further validated the system's strengths—such as transparency and voter trust—while acknowledging challenges like infrastructure readiness and legal considerations. Overall, the model offers a secure, scalable, and inclusive framework for electoral reform in emerging democracies.

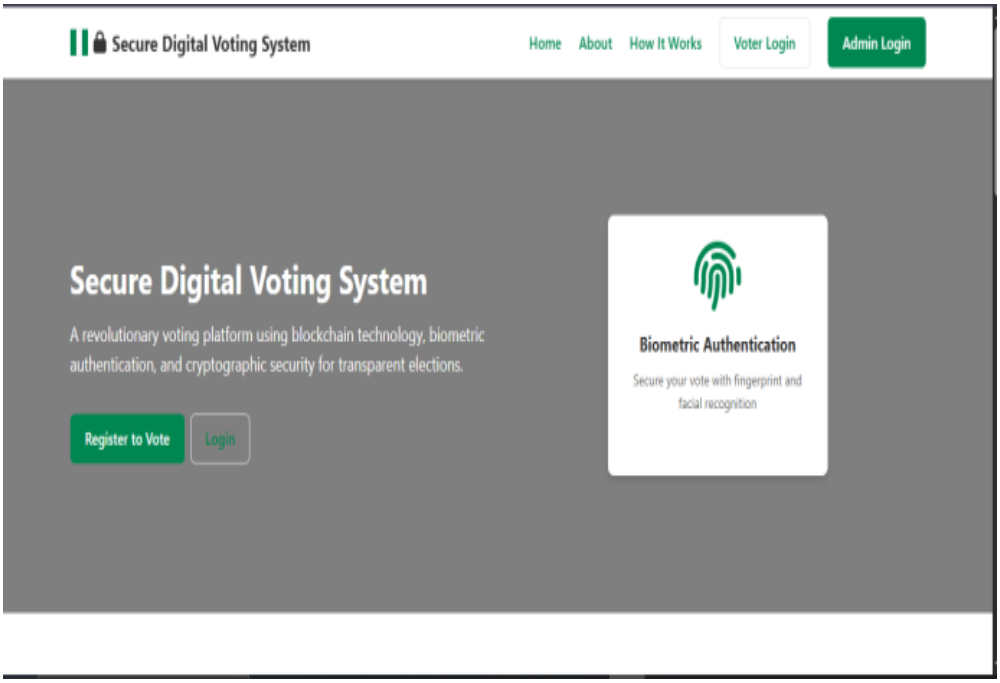

Figure 7: Homepage of a secure digital voting system

Figure 7 shows the homepage of a "Secure Digital Voting System" designed for transparent elections. It highlights a platform built with blockchain technology, biometric authentication (fingerprint and facial recognition), and cryptographic security. The page features navigation links, a prominent description of its secure and revolutionary features, and call-to-action buttons for voter registration and login, emphasizing a modern and trustworthy approach to digital voting.

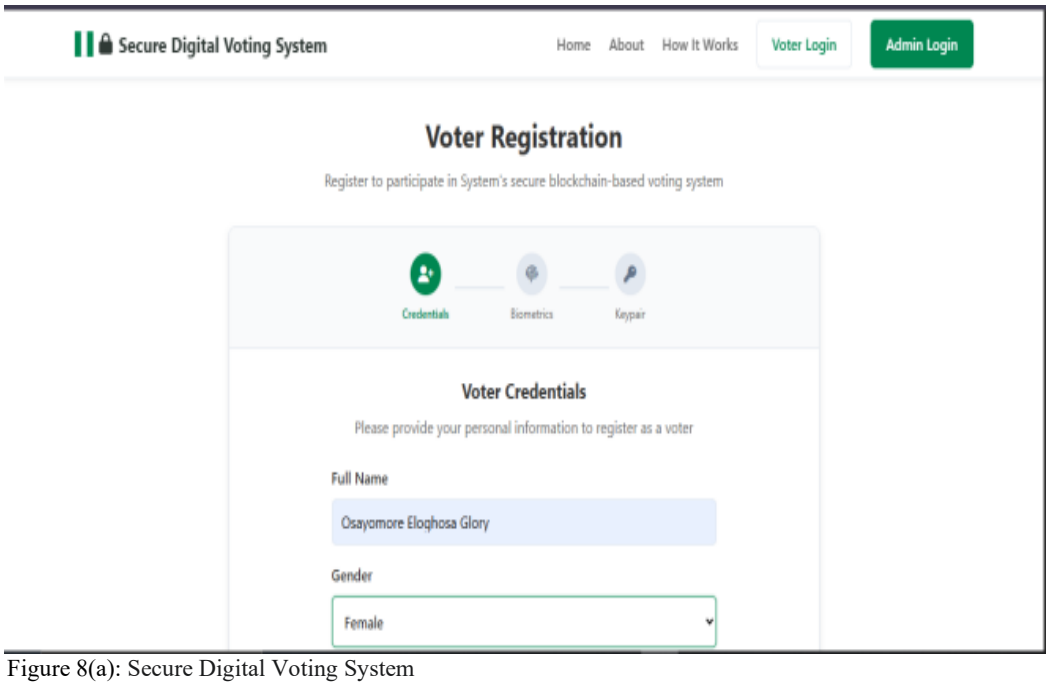

Figure 8(a): Secure Digital Voting System

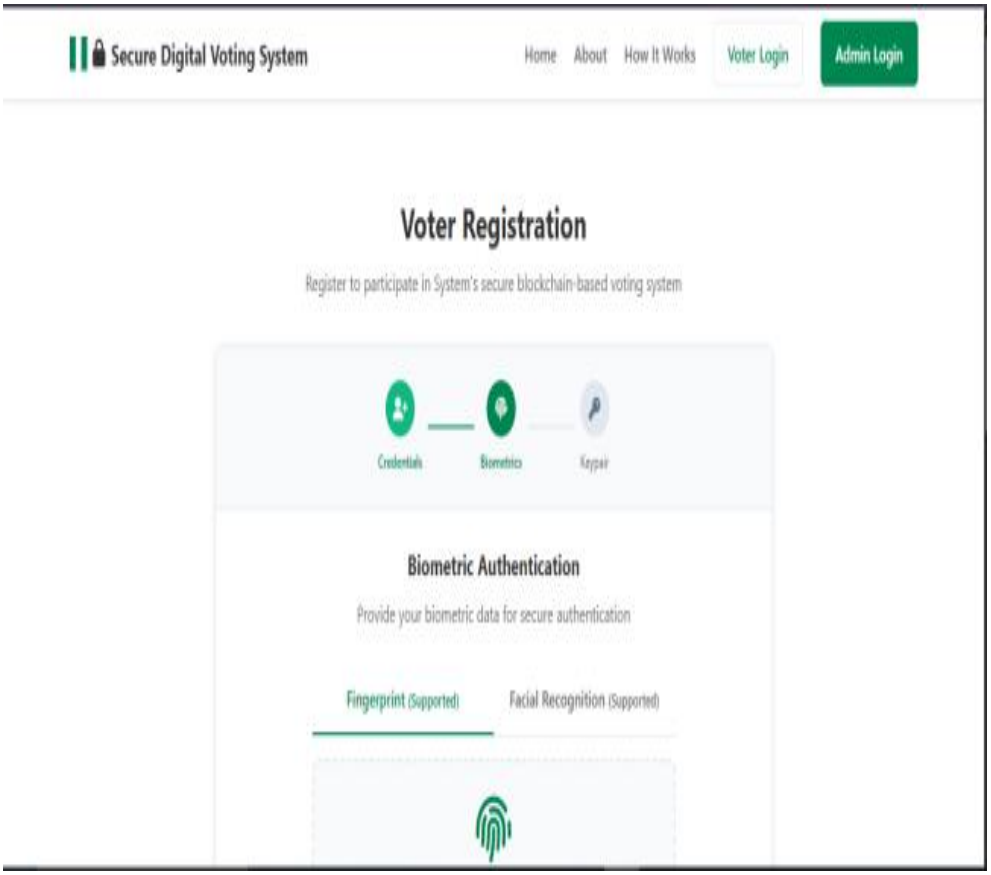

Figure 8(b): Secure Digital Voting System

Figure 8 depicts is a modern e-voting platform designed to ensure transparent and tamper-resistant elections by integrating blockchain technology and biometric authentication. Blockchain provides an immutable and verifiable ledger for vote recording and tallying, while fingerprint and facial recognition are employed to prevent voter fraud, such as duplicate voting and identity theft. The voter registration process is structured as a multi-step procedure, beginning with the input of personal credentials and followed by the collection of biometric data. This approach guarantees that only eligible and uniquely identified individuals can participate in the electoral process. The system interface guides users through this secure journey, emphasizing transparency, security, and trust from the homepage through to final vote casting.

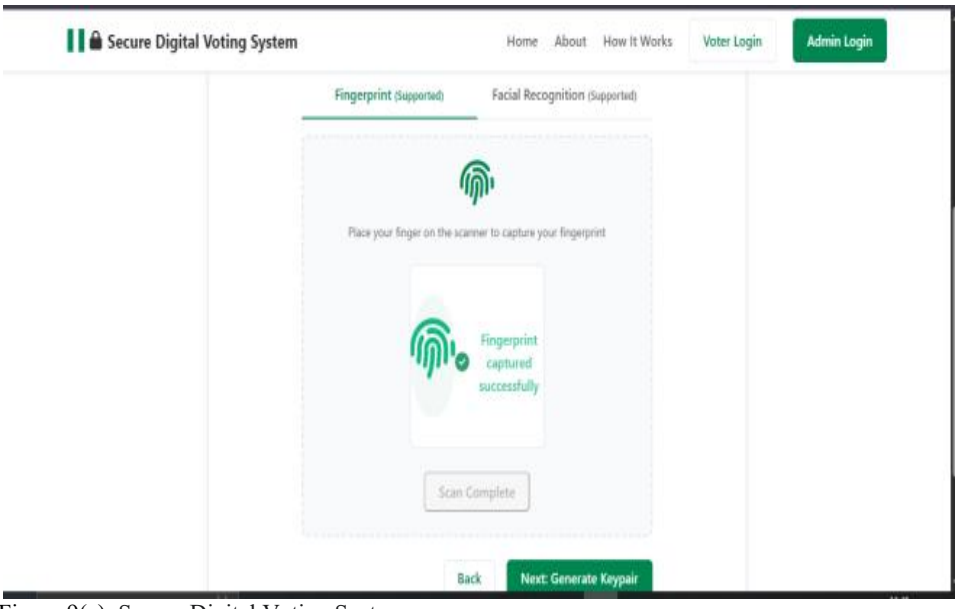

Figure 9(a): Secure Digital Voting System

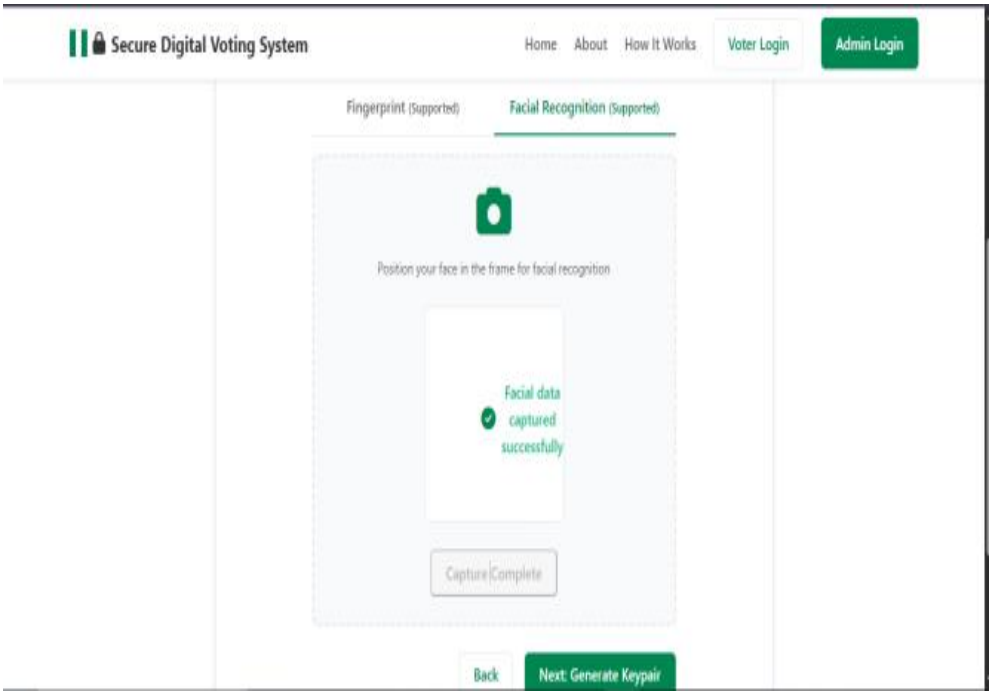

Figure 9(b): Secure Digital Voting System.

Figure 9 depicts a key phase in the secure digital voting system, the biometric authentication process using fingerprint and facial recognition. Upon successful capture and validation of biometric data, the system prompts users to proceed to the "Generate Keypair" step, marking the transition to cryptographic vote security. This illustrates the system's multi-layered approach, where biometric verification serves as a critical prerequisite to generating secure cryptographic credentials for casting votes, thereby ensuring both voter authenticity and ballot integrity.

Discussion

This study presents a comprehensive framework for a blockchain-based electronic voting system enhanced with fingerprint and facial recognition, aimed at resolving core deficiencies in conventional and existing electronic voting infrastructures, particularly voter impersonation, fraud, and lack of transparency. By combining blockchain's decentralized, immutable ledger with real-time multimodal biometric authentication, the system ensures tamper-proof vote recording and robust identity verification. Tailored to Nigeria's electoral landscape and aligned with the Independent National Electoral Commission's (INEC) legal mandates, the system enhances both identity assurance and data integrity, thereby reinforcing the "one person, one vote" principle and promoting public trust in electoral processes.

The research employs a mixed-methods approach, integrating qualitative system design and SWOT analysis with quantitative evaluation using IBM SPSS. Real-world electoral data from the 2024 Edo State gubernatorial election, specifically voter registration statistics, Permanent Voter Card (PVC) collection rates, and polling unit distribution, provided empirical grounding. Findings revealed significant disparities in voter engagement across Local Government Areas (LGAs), particularly in the collection of Permanent Voter Cards (PVCs) and voter registration volumes. For instance, while Ikpoba-Okha recorded the highest number of registered voters (399,891), it also had the largest number of uncollected PVCs (87,819), indicating a potential gap in voter mobilization or access. Similarly, Oredo, with 356,541 registered voters, had 82,851 uncollected PVCs. In contrast, LGAs like Esan Central and Igueben reported much lower registration figures and significantly fewer uncollected PVCs, suggesting more effective distribution or smaller population sizes. These contrasts point to uneven electoral engagement and logistical inconsistencies across the state, which the proposed blockchain-based system seeks to address by enabling secure and remote digital participation.

Findings revealed significant disparities in voter engagement across Local Government Areas (LGAs) like Ikpoba-Okha and Oredo, where logistical inefficiencies impacted PVC collection. The proposed digital framework addresses such barriers by facilitating remote biometric-based digital participation, particularly for citizens affected by geographic, physical, or socio-economic constraints, thereby fostering electoral inclusivity. The architectural design guarantees end-to-end encryption of ballots, decentralized consensus mechanisms for vote validation, and audit trails accessible to authorized stakeholders, while safeguarding voter anonymity. Despite acknowledging limitations such as infrastructure readiness, biometric variability, and data privacy concerns, the study positions its solution as scalable, adaptable, and policy-relevant. With strategic regulatory support, digital literacy efforts, and privacy-preserving technologies, the integration of blockchain and biometrics offers a transformative pathway toward modernizing electoral systems, particularly in democracies facing credibility challenges. The findings contribute significantly to the interdisciplinary domains of e-governance, cryptographic security, and biometric computing, advocating for the adoption of secure, transparent, and inclusive digital voting solutions.

CONCLUSION

This study proposes a robust framework for a blockchain-based electronic voting system enhanced with fingerprint and facial recognition technologies to address persistent vulnerabilities in conventional and electronic voting methods. By integrating decentralized ledger technology with biometric authentication, the system ensures secure voter identity

verification, immutable vote recording, and transparent tallying. Empirical evaluation using data from the 2024 Edo State gubernatorial election analyzed via IBM SPSS and SWOT methodology demonstrates its effectiveness in improving transparency, scalability, and voter trust. While implementation challenges such as infrastructure readiness and data privacy exist, the research offers a scalable and policy-relevant solution for enhancing electoral integrity in emerging democracies. It positions blockchain-biometric integration as a transformative foundation for secure, inclusive, and tamper-resistant voting systems in the digital age.

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