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A SECURE AND SCALABLE FRAMEWORK FOR IMPLEMENTING ELECTRONIC VOTING AND E-GOVERNANCE IN PAKISTAN

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ABSTRACT

The Digital Voting System (Digi Vote) is a mobile-friendly, scalable, and secure electronic voting technology designed to improve the fairness of Pakistan's municipal elections. Long lines, human error, restricted accessibility, and vote manipulation are just a few of the inefficiencies that plague traditional voting systems and lower public involvement and trust. Utilizing current 5G / beyond 5G mobile networks and connecting with the National Database and Registration Authority (NADRA), Digi Vote overcomes these obstacles by enabling real-time voter verification via face recognition and CNIC-based authentication. To improve access security, a second OTP layer is used. The platform ensures inclusive participation, particularly for voters with physical limitations, by supporting both remote and in-person voting inside Pakistan. Transparency and auditability are guaranteed by real-time result monitoring, and votes are safely encrypted and kept in a tamper-evident ledger. Digi Vote, which was created utilizing the Design Science Research Methodology (DSRM), integrates biometric validation, encryption, mobile technology, and system design into an intuitive user experience. The design, implementation plan, and assessment of Digi Vote are presented in this method article, providing a strong foundation for safe, reliable, and easily accessible digital voting in Pakistan's developing e-governance environment.

INTRODUCTION

The idea of using electronic technology for political elections was conceived many years before the Internet was created in the late 1980s, and it was immediately followed by the introduction of commercial Internet service providers (ISPs) and the implementation of the ARPANET and NSFNET. Midway through the 19th century, a variety of voting machines (VM) were created worldwide as a result of these previously unheard-of developments in instrumentation, computer science, and artificial intelligence [1]. The majority of Pakistan's general elections have raised concerns about the impartiality and legitimacy of the Election Commission of Pakistan (ECP). Following the May 2013 general elections, allegations of widespread, coordinated election tampering sparked a controversy. A Parliamentary Committee for Electoral changes was established by the government in 2014 as a result, and it solicited ideas and recommendations for electoral changes that addressed a range of election process topics. The committee also asked the public and interested parties to provide suggestions for enhancing the way general elections are conducted and carried out, including the application of cutting-edge technologies like the Biometric Voting System (BVS) and Electronic

Voting Machines (EVM), which will be the main focus of this research study [2].

Because of Western philosophy, many people think that the Islamic world is now experiencing democratic leadership. But according to a number of academics, Islam has intellectual and practical origins in democracy, and the Quran's teachings lend credence to this theory. For instance, Allah (SWT) prohibited Prophet Muhammad (SAW) from making decisions without first seeking input from his companions and consistently solicited their perspectives before reaching a decision as a group [3]. The indirect or indirect techniques are the two distinct approaches used to elect the representatives. Voters use the direct approach to participate in the elections. As a result, voters do not participate directly in indirect elections. Elections are conducted using several techniques. There are two opposing viewpoints that consistently emphasize bottom-up functions and public opinion influencing and strengthening others. Voting is essential in human affairs. Political development is a protracted process of change since it doesn't start overnight [4]. Electronic voting, or "E-voting," is the use of electronic technologies to conduct elections so that voters may cast their ballots with ease [5]. A subset of citizens, either chosen or mandated, administer each nation [6]. Under a single, large independent variable, electioneering and electoral politics are dependent variables. Antagonism between Bhutto and Zia, which might be seen as a hypothesis, proved to be a turning point in the country's future history [7]. Numerous topics are covered in the extensive research "Exploring Social Media and Other Crucial Success Elements of Attitude towards Politics and Intention for Voting in Pakistan" seniors may communicate with one another and use their elected staff through e-participation, which is a key factor in expanding political prospects. Following the September 11, 2011, attacks, Pakistan pioneered e-participation. Research of this type aims to comprehend Pakistani behavior and intention about the impact of the social press as well as other important factors on political attitude and intention to vote [8]. Elections are crucial in every democratic nation in the globe because they provide the general populace the ability to choose their own leaders. In essence, it is a referendum to hold the politicians responsible. By utilizing their voting power to select the most qualified candidate to lead the state, elections give the general public a platform to voice their political opinions [9]. The study sought to compare election laws, determine the legal ramifications of EVM adoption, and offer suggestions for updating them. Despite the fact that the legal impact of EVM was only 18 percent, we may infer from our earlier research that EVM may be implemented in Pakistan with great success if we take into account all other elements, such as political, social, and technological issues [10]. Voters can utilize Electronic Voting Machines (EVMs), which resemble ATMs or personal computers, to cast their ballots. EVMs employ a keyboard, touch screen, or a pointer to mark their votes [11].

Poor execution, ongoing fraud and corruption, and a conspicuous lack of transparency plague Pakistani elections. Polls are usually controversial and often lead to violence, public unrest, and political impasse. Such incidents have a detrimental effect on civic engagement and democratic trust, as well as voters' faith in elected officials [12]. Internet-based applications and systems that facilitate a wide range of social activities are rapidly growing in today's society [13]. In the age of digital innovation, the way people and organizations interact, share information, and rally support has changed dramatically. Particularly in emerging democracies like Pakistan, this paradigm change has had a significant influence on the political environment [14]. Electronic voting systems have been the subject of intense study for decades, with the main objective being data preservation and election cost reduction through the maintenance of security conditions and adherence to election integrity regulations [15]. Free and fair elections are crucial to Pakistan's democracy. Elections are the cornerstone of a democratic government and promote good management. Since free, fair, and credible

elections ensure that the will of the people is expressed in the choice of their representatives, a democratic political system is hard to envision without them [16].

A concise description of the issue this study seeks to solve is given at the beginning of the paper, which is followed by a review of the body of research on electronic voting and e-governance systems. The full implementation plan that outlines the system architecture and main technologies utilized follows the framework of the suggested approach for creating the Digi Vote system. Following the data or simulations produced during testing, the report gives the assessment criteria used to gauge system performance. The report concludes with closing observations and recommendations for further research after a discussion of the results, limitations, and practical implications.

2. Literature Review:

Pakistan's migration from manual to digital voting has been influenced by technology innovation, regulatory changes, and pilot initiatives. Digi Vote is Pakistan's first organized attempt to institutionalize electronic voting, claim [1]. Modules for result gathering, verification, and registration make up this system. The actual difficulties encountered during the pilot stages are described in length by [4], who emphasize infrastructural and public trust concerns. Likewise, [30]. Stress how digital platforms may improve transparency and lower logistical

In order to avoid fraud and authenticate voters, the National Database and Registration Authority (NADRA) is essential. NADRA's biometric database, which includes fingerprints and face recognition, enables trustworthy identification verification during elections, according to [26], [32]. Digi Vote's integration with the system improves voter trust and security. However, there are notable drawbacks, including unequal implementation in rural regions and problems with internet access [25].

A preventive against electoral fraud has been advocated: biometric authentication. Secure access to voting systems is ensured via fingerprint and iris scanning, according to [19], [21]. By integrating these technologies with NADRA, voter validation may be done in real time. However, technological limitations like data discrepancies and scanner malfunctions raise concerns regarding reliability in various electoral contexts. The necessity for technology audits and data privacy legal frameworks is critical [18].

One fundamental worry is the security of computerized election systems. Cyber-attacks, data breaches, and vote manipulation are among the dangers highlighted by [17]. Because blockchain technology is impenetrable, it is advised for secure vote storage [27]. Two-factor biometric verification and encryption are also suggested as protection strategies. Pakistan should implement multi-layered data governance systems to guarantee voter privacy and confidence [28]. The design of Digi Vote incorporates biometric verification and modular components, making it suitable for Pakistan's election system according to [1]. The system improves real-time result reporting and transparency [23]. Investigate the usage of cloud computing for scalability, whereas [31]. Suggest integrating AI to identify abnormalities during voting. These developments mark a significant advancement in Pakistan's infrastructure for digital governance.

It's critical to learn from global models. Estonia's electronic voting system is often referenced as a world standard [22]. Details Estonia's gradual implementation of smart card-based authentication for safe online voting. On the other hand, trust and logistical problems beset the UK's trials [33]. Lessons in decentralized voting architecture applicable to Pakistan's rural areas can be learned from Ghana's recent mobile-based e-voting scheme [7].

Table 1 Summary of LR

References	Key Focus	Methodology	Main Findings
[1]	Modular e-voting system	System design and simulation	Effective in real-time tabulation and verification

[4]	Pakistan E voting nature origin and applications programs	Field surveys	Infrastructure gaps and limited digital literacy
[17]	Secure digital storage	System simulation	Recommended decentralized architecture
[18]	Voter identity	Field test	Strong results in urban zones
[19]	Religious compatibility of biometrics	Case study in Bangladesh	Increases democratic trust through religious alignment
[20]	Legal gaps	Doctrinal review	Suggested data protection reforms
[21]	Data reliability	Technical study	Strengthened integrity but noted access barriers
[22]	Secure e-voting rollout	Legal and technical review	Phased implementation ensures acceptance
[23]	System scalability	Infrastructure analysis	Advocated hybrid cloud for flexibility
[24]	E-ID systems	International comparison	Biometric-based models are optimal
[25]	Biometric reliability	Impact study	Improved integrity, but rural barriers persist
[26]	Biometric integration	Technical evaluation	Enhanced voter authentication accuracy
[27]	Tech applications	Use case synthesis	Ideal for immutable vote records
[28]	Cybersecurity	Case analysis	Urged multi-tiered security layers
[32]	Voter identity tech	Prototype implementation	
[29]	Mobile e-voting framework	Comparative analysis	Potential for rural deployment in Pakistan
[30]	Digital reforms	Policy evaluation	Found digital tools effective in audits
[31]	Smart analytics	Proposal model	Enhances fraud detection in real time
[33]	Voting channels and logistics	National trials	Exposed readiness issues and mistrust
[34]	Identity management	Usability testing	Noted efficiency gains, cost concerns

Recent developments in electronic voting (e-voting) systems have shown promise in enhancing the security, accessibility, and transparency of elections. Numerous studies have examined the technological and sociopolitical aspects of these systems in South Asian and international contexts, providing insightful information pertinent to Pakistan's objectives for digital transformation.

The technological viability of scaled digital platforms was demonstrated by a modular e-voting system put out in [1], which demonstrated the efficiency of real-time tabulation and verification through system design and simulation. In a similar vein, [17] underlined the necessity of safe digital storage by suggesting a decentralized architecture to improve the integrity and resistance to manipulation of voter data. Infrastructure studies like [23] promoted hybrid cloud solutions for scalability and deployment in order to guarantee system longevity and flexibility.

Local context studies have highlighted critical challenges. Low levels of digital literacy and inadequate infrastructure were identified as the main barriers to the effective deployment of electronic voting in a field study carried out in Pakistan [4]. Additionally, theological and legal evaluations [20], [22] highlighted the necessity for gradual adoption techniques to achieve public acceptability and legal compliance while pointing out important inadequacies in data protection rules.

In e-voting, identity verification is still a top priority. While technical assessments [25], [26] demonstrated the increased authentication accuracy brought about by biometric integration, field experiments [18] verified the robust performance of voter identity technologies in urban regions, despite observed challenges in rural outreach. Furthermore, based on a case study conducted in Bangladesh, it was shown that the religious compatibility of biometric systems [19] improved democratic confidence. This finding is very pertinent to the sociocultural context of Pakistan.

Security is yet another important factor. While [31] offered sophisticated analytics for real-time fraud detection, research in [28] recommended multi-tiered cyber security techniques to protect voter data and digital operations. Additionally, national-level experiments [33] and prototype

implementations [32] raised awareness of practical deployment challenges such channel variety, logistical readiness, and public confidence.

By providing a mobile-integrated, NADRA-backed, and biometric-secured voting platform that satisfies technological specifications and the sociopolitical context of Pakistan, Digi Vote aims to fill the gaps and overcome the difficulties noted in the literature.

3.Problem Statement

Pakistan's election system still has persistent problems, including long lines, manual voting, delayed counting, vote manipulation, and restricted accessibility, particularly for voters in distant areas and those with physical disabilities. These difficulties impair public confidence in democratic procedures and deter people from casting ballots. Although biometric databases, digital governance, and mobile technologies have advanced, the existing voting system is still paper-based and susceptible to fraud, manipulation, and inefficiency. Due to their lack of development or interaction with national identity systems, current digital solutions are not suited for secure and widespread implementation.

The lack of a strong, mobile-based electronic voting system that can safely identify voters, protect voter privacy, and allow for real-time vote casting and result calculation is a significant gap. In elections, NADRA's unified biometric and identification database is not used to its full potential. Additionally, the infrastructure that uses contemporary mobile networks like 5G / beyond 5G to enable distant but authorized participation is not safe enough. Election manipulation and inefficiency are still possible in the absence of a system that integrates tamper-evident data storage, secure transmission, and biometric verification. In order to meet the demands of Pakistan's e-governance environment, Digi Vote seeks to provide an integrated, safe, and scalable digital voting system.

4. Proposed Methodology

A key idea in problem-solving, the Design Science Research Methodology (DSRM) notion originated in engineering and the sciences with a foundation in artificial artifacts. By producing novel artifacts and developing design knowledge (DK) by coming up with creative answers to pressing problems, DSRM aims to advance and improve human understanding. This idea has helped practitioners and academic communities produce creative objects to address challenging societal issues. In addition to its many uses in engineering, business, and economics, the DSRM will soon be employed in machine learning and artificial intelligence architecture for system design. The next section provides an illustration of the DSRM Framework, which serves as the foundation for the creation of any DSRM architecture [1].

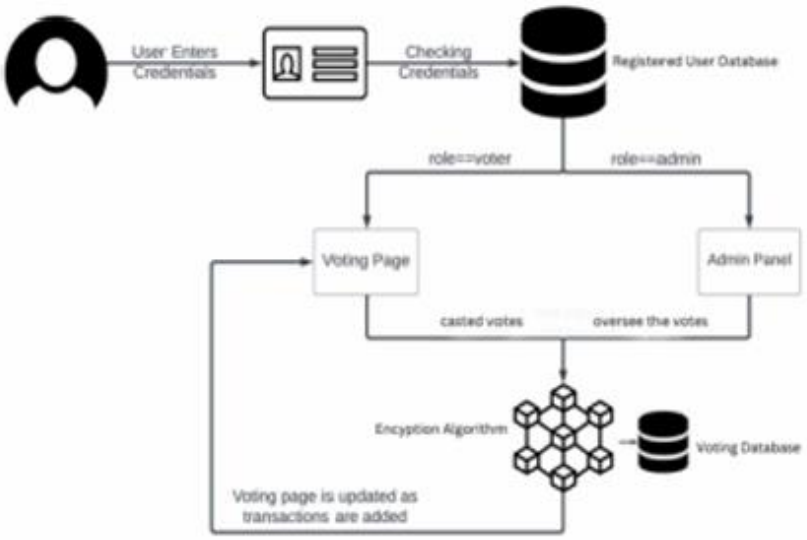


Figure 1 Digi Vote System Methodology Diagram

4.1Problem Identification and Motivation

Pakistan's electoral system has historically depended on manual, paper-based voting, which presents a number of difficulties, such as difficulty for voters who live far away or have disabilities, the possibility of ballot fraud and tampering, inefficient procedures, and delays in tabulating results. Critical examination of government reports, election processes, and noted voter discontent led to the identification of these problems. The efficiency required in contemporary governance systems is not reflected in voting procedures, which are still susceptible to manipulation despite the growing digitization of public services.

Leveraging Pakistan's vast biometric database, which is overseen by the National Database and Registration Authority (NADRA), is a crucial component of the country's current infrastructure and can help solve these issues. In a digital setting, this database can serve as the foundation for safe voter identification that is identity-verified [2]. A joint session of Parliament also passed legislation on November 17, 2021, allowing the Election Commission of Pakistan (ECP) to introduce Electronic Voting Machines (EVMs) and facilitate remote voting, including through partnerships with NADRA or similar bodies [16]. This marked a significant shift in policy.

Furthermore, in order to assess the viability, confidentiality, security, and financial ramifications of EVMs and Biometric Verification Machines (BVMs), the ECP is authorized under Section 103 of the Elections Act 2017 to carry out pilot projects utilizing these technologies [10]. These advancements establish a technological and policy framework that significantly encourages the creation of a mobile-based, safe, and transparent voting system, like Digi Vote, in order to update Pakistan's electoral infrastructure and increase political engagement.

4.2 Define Objectives for a Solution

In order to address the persistent problems with Pakistan's manual voting system, including limited accessibility, electoral fraud, and delayed results, this project intends to create Digi Vote, a mobile-based electronic voting platform that is safe, effective, and scalable. Enhancing the voting process through the use of national infrastructure and safe digital technology is the main goal.

First, by fusing OTP verification with biometric facial recognition, the system concentrates on safe voter authentication. By integrating with the NADRA national biometric database, this two-layered system makes sure that only valid voters can use the platform, greatly lowering voting fraud and impersonation. Secure identity verification using biometric technologies is

necessary for privacy-preserving electronic voting platforms, according to [36].

Second, to increase accessibility, particularly to underserved and rural people, mobile network infrastructure (5G / beyond 5G) is used. This mobile integration lessens logistical obstacles and permits wider democratic involvement. Stress that even in geographically dispersed electorates, blockchain solutions based on mobile devices may guarantee accessibility and transparency [35].

Lastly, tamper-evident audit trails and real-time result calculation are used to achieve data integrity and transparency. Keep in mind that in order to foster public confidence and safeguard voter anonymity, secure electronic voting systems must place a high priority on openness and verifiability [37].

4.3 Design and Development

The Digi Vote system was developed using a layered and modular design that combines secure backend processing, biometric authentication, and mobile technologies. In order to provide accessibility for a variety of user groups, the platform is designed to run consistently across Pakistan's 5G / beyond 5G network infrastructure and on widely available mobile devices.

At the presentation layer, a cross-platform framework (like Flutter or React Native) is used to construct a mobile application so that it works on both iOS and Android devices. The user interface for voter registration, biometric authentication, and casting a ballot is provided by this program. After being cross-checked with the NADRA biometric database, the voter's identification is confirmed by face recognition and an OTP issued to their registered cellphone number. Biometric authentication dramatically lowers identity fraud in digital voting systems, as [38] points out. Voter authentication, ballot rendering, and secure vote submission are handled by the logic layer. Votes are sent to the server after being digitally signed and encrypted. Confidentiality is guaranteed, and vote manipulation is prevented. In [37] asserts that end-to-end vote security and integrity can only be achieved through the use of digital signatures and encrypted channels. The data layer is made up of a secure backend server that keeps tamper-evident records of every vote. To provide openness and auditability, votes are saved using cryptographic hash algorithms. Future incarnations could use blockchain-like architecture to improve traceability and decentralization. Verifiable logs have been highlighted by researchers like [39] as being crucial to boosting public confidence and transparency in electronic voting systems.

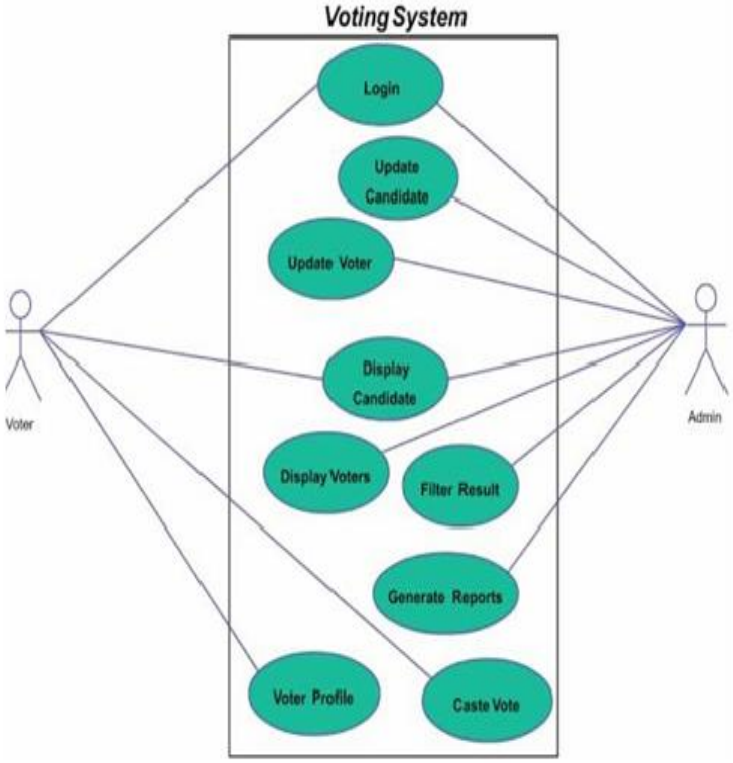


Figure 2 E-Voting System Model

The voter starts using an electronic voting system by going to the login screen and entering the necessary information, such as their CNIC number, OTP, or biometric information. The system instantly returns the voter to the main menu without allowing access if the credentials are invalid. After a successful login, the system verifies the voter's identity and ability to vote by comparing their information with the national database (such as NADRA). The interface enables the voter to safely cast their vote if the validation is successful and they haven't done it before. However, the system provides an error notice and stops the process if the validation fails because of mismatched information, past voting behavior, or data discrepancies. This prevents any additional action to assure the election's integrity.

5. Evaluation Criteria

Digi Vote's assessment is essential to ensuring that the system achieves its goals and functions well in an actual electoral setting. System access interface work process is showing in below diagram:

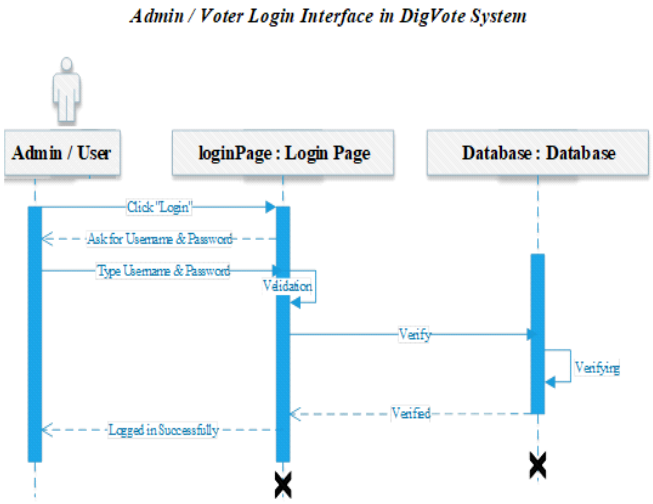
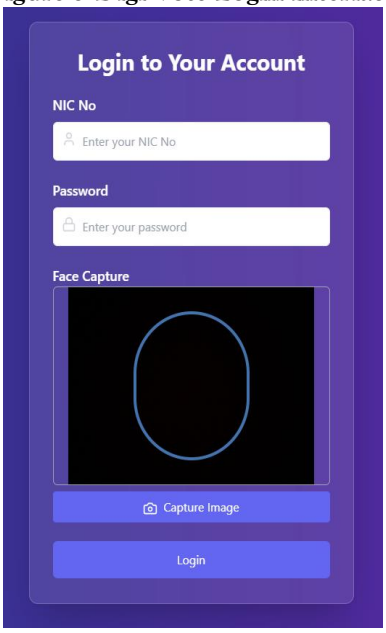


Figure 3 Digi Vote Login Interface



The following criteria have been identified to comprehensively assess the system:

5.1Security and Privacy

The system must be able to stop data breaches, vote rigging, and illegal access. Examining the robustness of encryption systems, the precision of biometric and OTP verification procedures, and the consistency of tamper-evident audit trails are all part of this. Tests will use simulated assaults and penetration testing to confirm that these security measures are reliable [37].

5.2 Accuracy and Reliability

In addition to properly recording votes, the system must consistently verify voter IDs by comparing them to the NADRA database. False rejection/acceptance rates and the dependability of real-time result calculation under various network conditions will be among the performance indicators [36].

5.3 Usability and Accessibility

User testing is used to evaluate the mobile application's usability, with an emphasis on accessibility for a range of demographics, intuitiveness, and interface design. Feedback sessions and surveys will be used to assess how well the design satisfies user demands.

5.4 Performance and Scalability

System latency, response times over 5G / beyond 5G networks, and the system's capacity to manage several simultaneous voting sessions during election seasons are all measured as part of the evaluation process. To make sure the solution scales effectively, stress testing will be carried out.

5.5 Transparency and Auditability

To make sure that every vote transaction is traceable and open to auditors and regulators, the accessibility and lucidity of tamper-evident records and audit trails will be assessed. This promotes both legal compliance and public trust [35].

6. Discussion

A positive move toward a safe, open, and easily accessible electoral system in Pakistan is represented by the creation and design of Digi Vote, a mobile-enabled electronic voting system. Through the use of OTP verification over 5G / beyond 5G mobile networks and biometric authentication through the National Database and Registration Authority (NADRA), Digi Vote offers a locally customizable solution that supports the government's goals for electoral reform and digital governance.

Digi Vote tackles a number of persistent issues with Pakistan's manual voting system, such as ballot stuffing, voter impersonation, and accessibility issues for those living in distant or disadvantaged regions, according to the results and implementation plan. With multilayer encryption and tamper-evident audit trails, its mobile interface, in particular, enables greater voter participation while preserving security and privacy.

Furthermore, this study maintains theoretical rigor and practical relevance by using the Design Science Research Methodology (DSRM). The evaluation criteria highlight Digi Vote's strengths in terms of usability, scalability, and performance all of which are critical for possible use in national elections. By facilitating real-time result processing, the technology enhances operational effectiveness and public trust while lessening the administrative load on the Election Commission of Pakistan (ECP).

However, this study also acknowledges the obstacles that still need to be overcome, especially with regard to public digital literacy, infrastructural preparedness in rural regions, and regulatory acceptability. Policy integration, real-election piloting, and ongoing security enhancements to combat changing cyber-threats should be the focus of future research.

Digi Vote offers Pakistan's democratic processes a revolutionary chance. Adoption may revolutionize civic involvement, increase election transparency, and establish a standard for other developing countries looking to implement safe, locally-specific digital voting systems.

Conclusion and Future Direction

This research presented Digi Vote, a mobile-based, secure electronic voting system that aims to improve Pakistan's election procedures by tackling the drawbacks of manual voting, including its inefficiency, inaccessibility, and fraud risk. Based on national needs, the system was built and assessed using the Design Science Research Methodology (DSRM). It included mobile network accessibility (5G / beyond 5G), biometric verification, OTP authentication, and NADRA database connectivity. By ensuring safe voter identification, data integrity, and wider accessibility, these characteristics work together to improve voting process transparency and confidence.

Digi Vote has a great potential to increase voting turnout, lower human error, and expedite vote counting and result reporting, according to preliminary simulations and assessments. However, further research will be necessary before full-scale deployment can occur. To assess the system's efficacy in practical settings, particularly in rural and low-connectivity locations, future

research should concentrate on trial testing it during local elections. In order to align the system with legal and policy frameworks, cooperation with the Election Commission of Pakistan (ECP) is also essential. To guarantee long-term success, investments in infrastructure, voter education, and security enhancements will also be crucial. By addressing these potential paths, Digi Vote may prove to be a crucial milestone in Pakistan's transition to an open and inclusive digital democracy.

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