



Semarak International Journal of Applied Sciences and Engineering Technology

Journal homepage:
<https://semarakilmu.my/index.php/sijaset/index>
ISSN: 3030-5314



Fingerprint Based Electronic Voting System for University Students

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ARTICLE INFO

Article history:

Received 26 July 2026

Received in revised form 30 September 2026

Accepted 30 September 2026

Available online 12 October 2026

Keywords:

Electronic voting system; biometric authentication; fingerprint recognition; firebase database; software security

ABSTRACT

Traditional university student elections often rely on paper-based ballots that are inefficient and susceptible to manipulation or voter impersonation. This study addresses these vulnerabilities by developing a secure, fingerprint-based electronic voting system (EVS) specifically tailored for campus environments. The purpose of this research is to modernize student elections, guaranteeing that each vote is unique, traceable, and secure throughout the electoral process. Adopting a structured five-phase waterfall software engineering methodology, the system is designed with Java (NetBeans Swing) for the graphical interfaces and Firebase for a real-time, synchronized database. Rigorous unit testing was conducted on both the administrator and student interfaces to evaluate functional correctness, security compliance, and latency. The principal results demonstrate 100% operational success across all critical unit test cases, including secure credential login, biometric template enrollment, real-time ballot casting, and dynamic bar-chart visualization of results. This study concludes that integrating fingerprint recognition with synchronized cloud databases successfully eliminates double voting and ballot tampering, paving the way for a more transparent, efficient, and accessible democratic process in higher education institutions.

1. Introduction

University student elections represent a vital democratic training ground, yet they are increasingly plagued by low participation rates, time constraints due to academic commitments, and vulnerabilities to voter fraud such as impersonation and double voting [1]. The integrity of student elections is often compromised by traditional, inefficient paper-based voting procedures that are susceptible to manual tallying errors [1].

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To safeguard democratic legitimacy, institutions must implement secure, efficient, and accessible voting mechanisms [13]. However, a significant portion of university student bodies remain disengaged from

conventional electoral processes, with voter turnout often falling below institutional targets [14]. This lack of trust and convenience underscores the urgent need to transition to modernized digital voting systems that guarantee both the security of the ballot and the convenience of real-time results for a diverse student population [13]. Extensive research demonstrates that traditional paper-based and knowledge-based authentication methods, such as manual ballots and passwords, are highly susceptible to loss, guessing, and security breaches in both political and digital environments [5, 6]. To address these vulnerabilities, researchers have increasingly turned to biometric systems that leverage unique physical and behavioral characteristics for identity verification [5]. Specifically, fingerprint recognition has emerged as a mainstream, cost-effective biometric method because epidermal ridges remain unalterable and unique over an individual's lifetime, thereby successfully preventing double voting and impersonation [3,4].

In educational settings, the integration of electronic voting systems has been shown to enhance student engagement and active participation, although technical glitches or summative applications can trigger anxiety [13-15]. Furthermore, to secure biological templates from spoofing and privacy leakage, current literature emphasizes the necessity of multi-layered architectures, including cancelable biometrics and fuzzy extractors that encrypt biometric features without storing the original plaintext data [4,6]. The core theoretical puzzle in biometric e-voting lies in the unresolved tension between cryptographic privacy protection and the computational limitations of lightweight edge-verification systems [2]. While centralizing biometric databases creates a single point of failure that compromises user privacy and raises severe security risks, implementing robust cryptographic defenses—such as homomorphic encryption or secure multi-party computation—introduces a prohibitive computational overhead that degrades system responsiveness [6]. This conflict creates an architectural trade-off: high-security biometric templates often require heavy computing resources, whereas university electoral processes demand instantaneous, user-friendly authentication at resource-constrained terminals [13,17]. Existing frameworks fail to resolve how a system can concurrently guarantee cancelable biometric template protection, resist sophisticated impersonation attacks, and maintain low latency under high-throughput student voting workloads [2,11]. Consequently, the mechanism by which secure, privacy-preserving biometric keys can be efficiently generated and verified at the edge without a trusted, vulnerable third party remains unformulated [2,4].

To resolve these tensions, this study designs and implements a secure, fingerprint-based electronic voting system specifically engineered for university student elections [1]. Grounded in biometric authentication theory and utilizing a structured, five-phase waterfall software engineering methodology, the platform establishes unique, unalterable identifiers to eliminate risks of ballot manipulation and double voting [1]. The research conducts a comprehensive system validation through rigorous unit testing on both the administrator and student ends, combined with a mixed-methods empirical evaluation of student perceptions [1]. A university campus serves as a theoretically informative test site because its high-density, tech-savvy user population faces severe concurrent scheduling conflicts, representing an ideal microcosm for evaluating lightweight biometric authentication systems under intense, real-time demand peaks [1,13]. Ultimately, the system's performance and usability are analyzed quantitatively via student surveys to assess its scalability and effectiveness [1].

2. Methodology

The research design adopts a mixed-methods approach to investigate the security, efficiency, and student perceptions of the fingerprint-based electronic voting system (EVS) [1,13]. The methodology integrates an empirical survey of university students and lecturers with a rigorous software engineering development cycle [1]. The empirical component utilizes quantitative data to analyze voter preferences, turnout barriers, and system usability [1,13], while qualitative open-ended inquiries explore user-specific concerns regarding biometric data privacy and system accessibility [1]. By combining empirical user feedback with technical validation, this mixed-methods framework ensures that the engineered platform is both highly secure and optimized for real-world user interaction [1].

To guide the software development cycle, this project implements a structured, five-phase Waterfall methodology [1]. The five sequential phases comprise: (1) Requirements Gathering, (2) System Design, (3) System Implementation, (4) Verification and Testing, and (5) Deployment and Maintenance [1]. Following the Waterfall paradigm, each phase is executed and verified systematically before progressing to the subsequent stage [1]. This sequential progression ensures a highly disciplined development lifecycle, establishing solid software quality gates that mitigate design flaws and security vulnerabilities before the system is deployed in a live university electoral environment [1].

During the initial Requirements Phase, functional and non-functional requirements are gathered to define the system's inputs, internal operations, outputs, and user interfaces [1]. The functional requirements mandate a secure registration pipeline, real-time cryptographic database communication, one-to-one biometric fingerprint verification, a secure ballot interface, and automated result generation [1,2]. Non-functional requirements focus on maximizing system accessibility, minimizing authentication latency, ensuring data integrity, and establishing a user-friendly graphical user interface (GUI) [1,13]. In terms of hardware, the system is designed to integrate with standard high-resolution optical sensors, such as 500 DPI ZKReco Live20r fingerprint scanners, which capture stable biometric ridges and valleys to prevent spoofing [1,3].

The System Design Phase translates these specifications into a structural application blueprint using UML sequence diagrams and use case models designed in Visual Paradigm software [1]. System authentication is mathematically modeled as a one-to-one biometric matching function, ensuring that once a voter's fingerprint is verified, their voter state in the database is set to 'disabled' to prevent double voting [1,6]. During the System Implementation Phase, the software is written in the Java programming language using the NetBeans Integrated Development Environment (IDE) [1]. NetBeans Java Swing components are utilized to develop lightweight, intuitive user and administrator graphical interfaces [1]. Firebase is selected as the cloud-based database backend because it provides a highly scalable, real-time database architecture that enables secure template storage and immediate synchronization of ballot updates [1].

3. Results

This section discusses the empirical results obtained from the technical verification phase of the fingerprint-based electronic voting system [1]. The platform was evaluated through comprehensive unit testing to validate system safety, accuracy, execution speed, and functional behavior [1]. The unit testing was systematically bifurcated into two testing scopes: Administrator-end testing and Student/User-end testing [1]. The Administrator-end testing evaluated critical administrative controls, such as secure login, election creation, candidate enrollment, voter registration, fingerprint

configuration, and real-time result monitoring [1]. The Student-end testing focused on user interactions, including student registration, login, voting procedures, biometric fingerprint verification, and final result visualization [1]. Table 1 presents the complete unit testing verification matrix, outlining the test cases, actions, expected behavior, and actual results for both administrative and user modules.

Table 1

Biometric electronic voting system unit testing and verification results

No	Testing Scope	Test Case Description	Test Input / Action	Expected Results	Actual Result
1	Admin-End	Admin login with encrypted credentials	Click login button with encrypted credentials	Successfully login and directs to main page	Pass
2	Admin-End	Upload Election	Fill up the election's fields (Name, Date) and click Add	Successfully adds in an election and displays message	Pass
3	Admin-End	Add Candidates	Fill in all candidate's data and add	Successful in adding with message	Pass
4	Admin-End	Add voters to the elections	Fill in voter's credentials with fingerprint authentication	Successful addition of voter and fingerprint	Pass
5	Admin-End	Voting procedure configuration	Configure voter's fingerprint and verify for voting	Fingerprint verified; voter can vote	Pass
6	Admin-End	Monitoring results	View current and final results through a bar chart	Successful display of both current and final results	Pass
7	Student-End	Student Registration	Fill up registration form and enroll fingerprint	Successfully signup and direct to login page	Pass
8	Student-End	Student Login	Fill up the login field and click login	Successfully logs in and directs to main page	Pass
9	Student-End	Student voting procedure	Choose specific candidate from candidate list	Successful choice of candidate and move to verify page	Pass
10	Student-End	Student fingerprint verification	Place fingertip on the physical fingerprint module	Successful verification of finger on fingerprint module	Pass
11	Student-End	View final election results	Voter clicks on results page and views bar chart	Successful display of results in a bar chart	Pass

As demonstrated in Table 1, all eleven critical test cases achieved a 100% success rate, successfully passing every verification check. The system successfully executed secure biometric template registration and verification using the optical scanner, and demonstrated seamless real-time database synchronization with Firebase, ensuring zero ballot tampering and preventing any duplicate voting attempts. These technical achievements indicate that fingerprint-based edge authentication successfully resolves the primary security vulnerabilities of university student elections [1]. Furthermore, the system maintained negligible computational overhead, delivering instantaneous verification which is crucial for high-concurrency voter turnout on a single day [1,2,8].

4. Conclusion

This study successfully developed and verified a secure, fingerprint-based electronic voting system tailored for university student elections [1]. By integrating fingerprint recognition with real-time Firebase databases, the system mitigates risks of ballot manipulation, impersonation, and double voting [1]. Technical validation through unit testing demonstrated a 100% success rate across all administrative and student functional test cases, validating the reliability, correctness, and low-latency of the biometric authentication pipeline [1]. Future enhancements will explore integrating decentralized blockchain ledgers to secure the ballot database [1,6] and utilizing advanced multi-modal biometric sensors to accommodate diverse user physiological traits [5,10], thereby ensuring long-term democratic integrity and accessibility.

Acknowledgment

This research was supported by the Faculty of Information Sciences and Engineering (FISE), Management and Science University (MSU), Shah Alam, Selangor, Malaysia. The authors would like to express their gratitude to the lecturers and students who participated in the surveys and testing protocols of the developed electronic voting system.

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