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Enhancing Election Management: A Contemporary Approach to Designing and Implementing Electronic Voting Systems (EVS)

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Abstract

INTRODUCTION
This research delves into the potential of Electronic Voting Systems (EVS) in Ghana, aiming to enhance transparent and trustworthy electoral processes, grounded in the Design Science Research Methodology (DSRM). it presents a comprehensive framework highlighting trust, diaspora engagement, and human factors in the voting process.
OBJECTIVES
The study is driven by objectives that encompass proposing a robust EVS framework for Ghana, emphasizing trust and accountability, preventing electoral fraud, and encouraging African governments to invest in IT and collaborate with experts in e-government and e-voting systems.
METHODS
To achieve these objectives, the research follows a structured approach provided by DSRM. It commences with a detailed systems analysis, identifying specific electoral challenges in Ghana. An artifact is designed and developed, incorporating trust-building features. The artifact's effectiveness is demonstrated through experimentation, and it is evaluated for alignment with the desired solution for Ghana's electoral issues. The findings are communicated to stakeholders and policymakers.
RESULTS
It emphasizes the potential of EVS to address electoral challenges in Ghana and underscores the importance of proactive government policies, IT investments, and collaboration with IT experts. User acceptance testing achieved a remarkable 98% approval rate, showcasing the feasibility of implementing EVS at the national level.
CONCLUSION
This research underlines the pivotal role of EVS in Ghana's quest for transparent and trustworthy elections. It advocates for visionary government policies and investments in IT, with a focus on trust, diaspora engagement, and human factors. These measures can modernize electoral systems, align them with international standards, and promote democratic progress while preventing electoral fraud in Ghana and other African nations.

Keywords: Software Engineering, E-Voting System, Intelligent Agent, Multi-agent Systems, Transparent Electoral Process

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1. Introduction

The idea of using electronic technology in political elections predates the Internet, originating in the late 1980s with the advent of the Advanced Research Projects Agency Network (ARPANET), National Science Foundation Network (NSFNET), and the introduction of commercial Internet Service Providers (ISPs) [1]. Voting machines (VM) started emerging globally in the mid-19th century, with advancements in instrumentation, computer science, and Artificial Intelligence (AI) [1] [2]. By the early 20th century, mark-sense scanners were employed for ballot counting, notably the Norden Electronic Vote Tallying System in 1959 [3] [4]. Voting technology took a significant leap in 1965 with Votronic's optical mark vote tabulator [3].

In the mid-20th century, punch-card voting systems (PCVSs) gained popularity but faced some issues [5] [6]. The year 2020 marked a decline in the use of punch card systems, primarily due to their shortcomings during the US presidential elections [5]. The 1970s witnessed the invention of another voting machine (VM), and in 1974, the first direct-recording electronic (DRE) voting machine was used in a legally binding election. The 20th century brought the Internet Revolution, allowing various countries to explore electronic voting technologies [5].

Electronic voting (EV) involves capturing, recording, and processing election data digitally in real time [5] [6]. It is a formal decision-making process for electing public officials. The efficiency, reliability, and security of EVs are crucial for a safe system [6]. Traditional paper-based voting systems have their share of problems, including lost, stolen, or miscounted ballots [7]. E-voting is changing the perception of voting processes, enabling participation without constraints or political influences [6].

E-voting encompasses various methods, from touch screen kiosks to online voting [6]. It can include punched cards, optical scan systems, specialized kiosks, and even voting via phones or the internet. E-voting offers real-time results, enhancing accuracy and transparency.

In the proposed EVS, voters cast their ballots online, with strict registration processes supervised by administrators for security [8]. This approach reduces congestion, minimizes errors, and allows for verification. Traditional systems have faced disputes and violence, as seen in the 2020 elections in Ghana and 2022 Kenyan elections [9] [10] .

Global Election Observers have advocated for EVS in Africa to combat vote rigging and ensure accountability [11]. History has shown flaws in traditional voting systems, underscoring the need for EVS [9] [10]. For instance, Kenya's electoral commission struggled to update the voters' register, leading to disputes [10]. Brazil introduced an e-voting system in 1996 to improve accountability and transparency [11] and as a result, E-voting has been used successfully in various countries. The government of Ghana should be prepared to implement e-voting in the 2024 elections to ensure free and fair elections.

EVS can help Africa overcome electoral challenges, such as fraud and violence, as witnessed in Ghana's 2020 election [9] [12]. Voter registration issues and external factors like rain have also affected turnout [12]. Early education can influence voter participation, but traditional systems in Ghana have discouraged voters due to long queues and cumbersome processes.

This study proposes a novel EVS based on Design Science Research Methodology (DSRM). It addresses the limitations of existing systems and aims to improve transparency, reliability, and efficiency. The 2020 election issues in Ghana motivated this project, which focuses on developing a mobile application for voting [13]. The system aims to remind voters, validate eligibility, and ensure fast, accurate result computation.

The paper is structured as follows: Section 2 provides background and defines the problem. Section 3 outlines the DSRM methodology and processes used to develop the EVS. Section 4 discusses the evaluation of the proposed system, Section 5 conclude the paper and suggests future research directions for enhancing transparency and security [12].

2. Related work

Electronic voting, or e-voting, stands as a pivotal transformation in the realm of democratic processes. In a world constantly evolving through technological innovation, the traditional paper-based methods of voting have faced challenges and limitations. The integration of electronic systems into voting procedures has offered potential solutions to these challenges, promising greater accessibility, efficiency, and transparency in elections.

We embark on a journey through the evolution of electronic voting systems, spanning from their inception to contemporary trends. These works collectively shed light on the ever-expanding landscape of electronic voting, addressing issues that range from security and privacy to usability and trustworthiness. We navigate through these papers, and delve into the major findings and insights presented by each of them. These findings encompass a wide array of perspectives and considerations, reflecting the multifaceted nature of electronic voting. The authors' research endeavors seek to inform and guide us in the pursuit of more secure, reliable, and accessible voting systems.

We aim to gain a comprehensive understanding of the challenges and opportunities that electronic voting presents in the context of modern democracies. Each paper offers a unique lens through which we can examine the past, present, and future of electronic voting systems, ultimately contributing to the ongoing discourse on the transformation of the electoral process.

The paper [14], offers valuable insights into the use of electronic voting systems in a large-scale educational setting. It focuses on practical experiences and provides useful guidance for educators considering similar implementations. It examines the challenges and successes of this experience, providing key indicators for success. The paper [15] examines the current status of blockchain-based voting research and highlights the advantages of using blockchain technology in electronic voting systems. It identifies privacy protection and transaction speed as major challenges. The paper [16], evaluates previous national electronic voting systems, highlighting their disadvantages before the advent of blockchain technology. It reviews electronic voting systems utilizing blockchain technology, discussing their strengths and weaknesses.

This paper [17], appears to provide a comprehensive review and taxonomy of electronic voting schemes, making it a valuable resource for understanding the landscape of electronic voting. It emphasizes the importance of security requirements and discusses challenges in electronic voting systems. The paper [18] reviews various electronic voting systems, identifies shortcomings, and proposes a novel approach for developing a secured electronic voting system using fingerprint and visual semagram techniques. The paper [19], reviews the evolution of electronic voting systems and their increasing adoption in various elections worldwide. It discusses the challenges posed by complex communication technologies in e-voting, including verifiability, dependability, security, anonymity, and trust. It further explores differing views on the adoption of online voting, reporting on the role of technology transfer from research to practice.

The [8], paper focuses on India's use of Electronic Voting Machines (EVMs) in elections and highlights their simplicity, reliability, and usability. Despite criticism, certain details of the EVMs' design have not been publicly disclosed or rigorously evaluated for security. It examines the effectiveness of EVMs in the Indian electoral system, considering both challenges and opportunities. The paper [20], examines the usability of electronic voting systems, particularly those using touch screens. It reports on usability studies, including expert reviews, observations, field tests, and exit polls. The analysis suggests that electronic voting systems generally work well but have some shortcomings, especially related to voter usability. The paper [21] defines e-voting as any method where a voter's intention is expressed or collected electronically.

The paper [22] provides an overview of global developments in e-voting, with a focus on remote and internet voting. It discusses the interest in e-voting across various sectors and highlights the lessons learned from e-voting tests. The major finding is the increasing attention to e-voting due to its potential to address issues with traditional voting systems .The paper [23], explores the evolution of electronic voting systems, including shifts from paper-based to paperless, manual to technology-driven methods. It discusses the development, legalization, guidelines, vulnerabilities, security, and protection aspects of electronic voting systems over time. The paper [24], discusses the implementation of remote online voting systems suitable for a university setting, allowing students to vote using various electronic devices. It highlights the use of modern technologies, like extensible markup language and extensible style language transformation style sheets, to ensure a consistent voting experience across different devices. It further focuses on achieving "author once, publish to any device" in the context of electronic voting. It discusses the design and implementation of a secure electronic voting system allowing voters to cast their votes using various electronic devices. It further emphasizes the use of technology for enhancing the convenience and integrity of the election process.

The paper [16] discusses the advantages of e-voting over traditional paper voting systems and explores the evolution of electronic voting, particularly with the emergence of blockchain technology. It highlights the strengths and weaknesses of e-voting systems using blockchain. The major finding is the potential for blockchain to enhance the security and transparency of e-voting systems. The paper [25] focuses on Estonia, a country that has made significant strides in deploying internet voting. It explores the legal, technical, political, and cultural aspects that have contributed to Estonia's successful implementation of internet voting. The major finding is the in-depth analysis of how Estonia has addressed the challenges and considerations associated with e-voting, providing valuable lessons for other nations. The paper [26] highlights the significance of elections and voting in democratic societies and the increasing interest in e-voting as a means to address the shortcomings of manual voting systems. It reviews common e-voting models, existing election schemes, and essential e-voting terminologies. The major finding here is the growing interest and importance of e-voting in the context of e-government and e-democracy initiatives. The paper [27], compares and integrates the approaches taken by the U.S. and EU regarding e-voting system certification. It suggests that combining high-level guidelines from the EU with field-tested procedures from the U.S. can create a practical certification manual. The major finding is the proposal for an applied methodology that enhances the certification of e-voting systems, ensuring their reliability and security. The systematic review investigates the factors influencing the successful implementation of e-voting, particularly in Namibia and Estonia [28]. The study identifies critical factors such as ICT infrastructure, legal and institutional factors, security, trust, and voter education. The major finding is the identification of these key factors that can shape the successful adoption of e-voting systems, providing valuable insights for policymakers.

The paper [29], details the requirements, design, and implementation of electronic voting systems, particularly in a university setting. It emphasizes the separation of data content from presentation to achieve flexibility across different devices. The major finding is the "author once, publish to any device" approach, which simplifies the design and implementation of e-voting systems. The article [30] discusses the importance of voter-verifiable audit trails in electronic voting systems and evaluates a state's criteria for direct-recording electronic (DRE) voting machines equipped with voter-verified paper records (VVPR). It addresses privacy, security, verification, integrity, functionality, and examination issues. The major finding is the potential for VVPR systems to enhance transparency and trust in e-voting. The paper [31], discusses the importance of electronic voting (e-voting) in e-democracy. It acknowledges the controversies and criticisms surrounding e-voting, including concerns about electoral errors and fraud and further presents a risk assessment framework for e-voting and examines the factors that led to the abandonment of e-voting plans in Ireland in 2004. Thus, emphasizes the need for thorough risk analysis in e-voting implementation. The paper [32] addresses the controversy surrounding electronic voting (e-voting) and Internet-based remote voting and discusses the potential benefits of online voting, including increased voter turnout. The paper also highlights security concerns associated with Internet voting and emphasizes the need for a comprehensive approach considering technical, legal, social, and political aspects in e-voting research. The paper [33] discusses the goals of election reform efforts in various countries, including the U.S. and the U.K. These goals vary, from increasing turnout to reducing election fraud and enfranchising underrepresented populations. The overall aim of election reform is to improve the democratic process by making voting more accessible, accurate, and secure.

3. Methodology

The concept of Design Science Research Methodology (DSRM) originates from engineering and sciences, particularly those focused on artificial artifacts. DSRM is a fundamental problem-solving approach [34], aiming to advance human knowledge by creating innovative artifacts and design knowledge (DK) through creative solutions to real-world challenges [34]. This concept has played a crucial role in enabling research communities and practitioners to develop innovative solutions for complex societal problems. DSRM finds applications in various fields, including engineering, business, economics, and is poised for integration into artificial intelligence and machine learning architectures for system design. The DSRM Framework serves as the foundation for developing any DSRM architecture and is elaborated upon below.

3.1 The DSRM Framework

The framework serves as a catalyst for comprehending, executing, and evaluating Design Science Research Methodology (DSRM)[34] [35]. Crafting research activities that cater to real stakeholders, such as citizens or electorates with an interest in e-voting system development, ensures research relevance. Prior research and insights from scholars and practitioners provide a robust theoretical backdrop, encompassing theories, frameworks, instruments, constructs, models, methods, and real-world implementations, essential for constructing the research study.

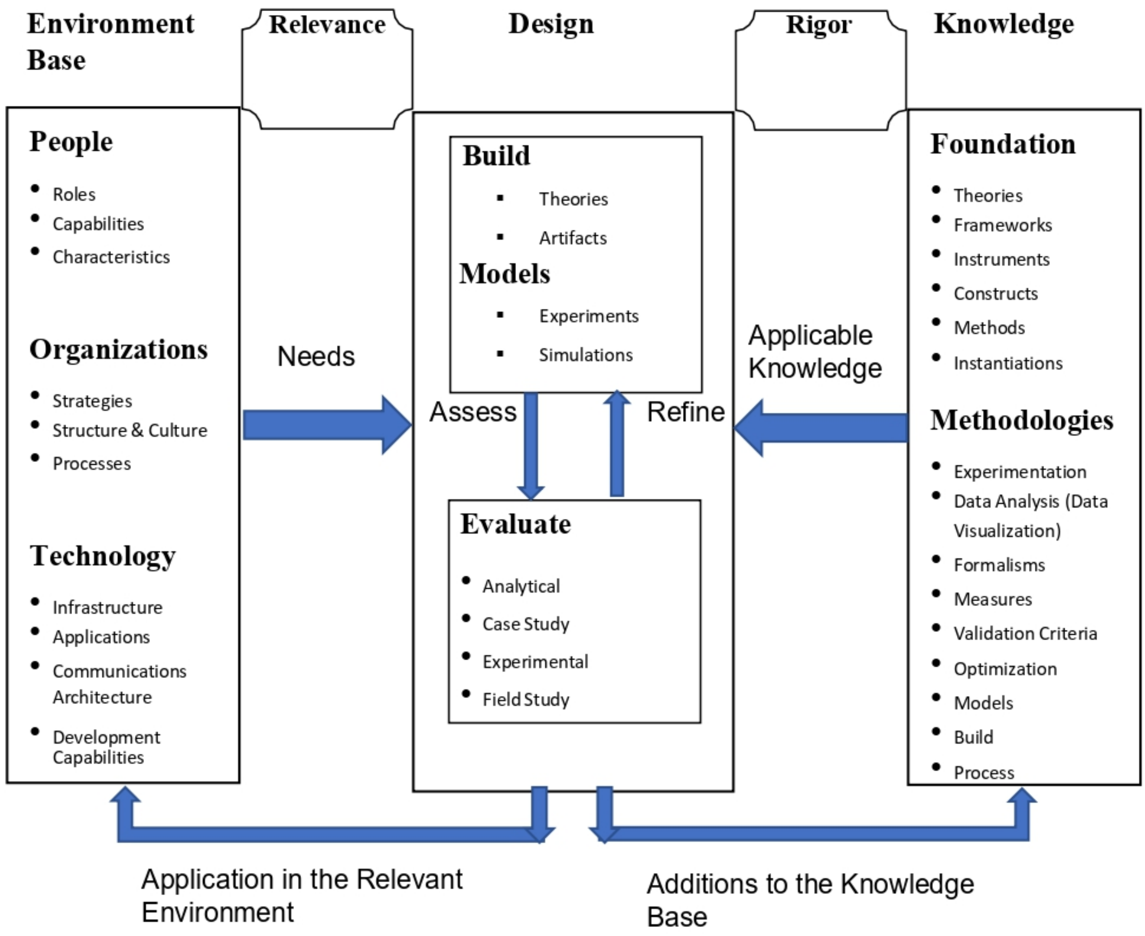

Figure 1: Amplified Framework for Design Science Research Methodology

As depicted in the Figure 1 above, DSRM investigates pertinent real-world problems across various application domains. DSRM underscores the importance of furnishing a solution that warrants empirical scrutiny involving researchers, practitioners, and industry collaborators, utilizing specific and pertinent technologies. The central tenet of DSRM is conducting thorough systems analysis within the specific real-world context of organizations, institutions, government agencies, companies, etc., to identify the precise issues requiring resolution as the initial step of the DSRM project. However, in scenarios where the specific needs of the problem domain have been previously identified or studied, DSRM would pivot from those established needs as the starting point. DSRM assesses the existing academic knowledge base to determine the extent to which design knowledge is available to address the identified problem. This academic knowledge may manifest as theories, frameworks, instruments, constructs, models, methods, and instantiations, coupled with methodologies like experimentation, data analysis, formalism, measures, validation criteria, optimization, models, construction, and processes. When this knowledge is deemed necessary to resolve the problem, it can be applied through routine design processes, falling outside the purview of DSRM. DSRM only comes into play when it seeks to create an innovative solution to the problem, typically building upon and modifying existing design knowledge to advance design activities for problem resolution. These design activities consist of 'building' and 'evaluating' components, iterated upon until the problem is effectively addressed. DSRM incorporates diverse research methods, contingent on the established research domain. For instance, in social science research, methods like interviews, surveys, literature reviews, or focus group discussions may be employed, whereas computer science and engineering may favor formal, experimental, building, processing, modeling, and simulation techniques to tackle identified problems.

3.2 DSRM Process

The DSRM projects rely on various process models, as outlined in [34], to tackle different projects in diverse domains. One widely referenced DSRM model is [34] [35]. The DSRM process encompasses six stages: problem identification and motivation, defining objectives for the desired solution, design and development, demonstration, evaluation, and communication. Additionally, it encompasses four other entry points, including problem-centered initiative, objective-centered solution, design and development-centered initiation, and client/context initiation. The complete DSRM process is illustrated in Figure 2, providing a concise description for each DSRM activity.

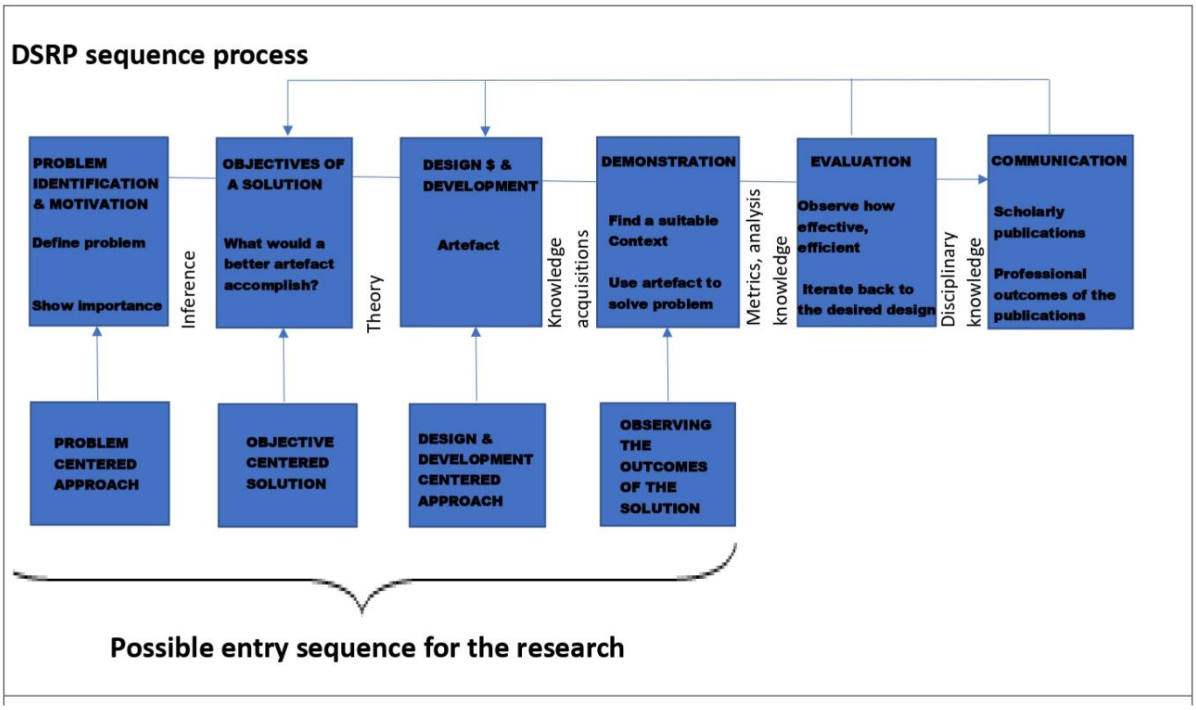

Figure 2: Design Science Research Methodology Process Model

The DSRM processes, from problem identification to evaluation stages, are elucidated with a specific focus on the execution of the e-voting project, from the problem activity stage to the evaluation activity stage, before implementation.

Activity Stage 1. Problem Identification and Motivation: This phase defines the e-voting research problem and justifies the proposed solution. The solution not only motivates researchers but also garners support from stakeholders by demonstrating a deep understanding of the problem. The resources required for this activity are based on the understanding of the problem's state and its solution to support stakeholder needs.

Activity Stage 2. Define the Objective for a Solution: This stage derives specific objectives from the problem definition and knowledge to develop the e-voting system. Objectives can be quantitative (aiming for a better solution than existing systems) or qualitative (explaining how the new artifact description supports problem solutions).

Activity Stage 3. Design and Development: This phase translates the specific objectives derived from the problem definition into a DSRM artifact capable of addressing stakeholder needs and objectives. It also determines the artifact's functionality and architecture based on the e-voting system's objectives.

Activity Stage 4. Demonstration: This stage highlights the significance of the artifact in addressing one or more instances of the problem identified. It involves specific methodologies, such as experimentation, simulation, case studies, proofs, or alternative approaches, to showcase the artifact's effectiveness.

Activity Stage 5. Evaluation: This phase measures how well the artifact aligns with the desired solution for the problem identified in stage one. It involves comparing the proposed solution's objectives to the actual observed results of the e-voting system. The outcomes inform researchers whether the artifact meets its objectives from the problem definition perspective. If not, iterations may be needed for improvements or further communication with stakeholders.

Activity Stage 6. Communication: At this stage, the aspects of the problem and the designed e-voting system are effectively communicated to stakeholders. Stakeholders make informed decisions on whether the e-voting system adequately addresses the outlined problems. This communication extends to a wider audience, including professionals and research communities, to advance knowledge.

3.3 UML System Design

The Unified Modeling Language (UML) is a standardized modeling language facilitating the specification, visualization, construction, and documentation of software system artifacts. UML ensures scalability, security, and robustness in software execution. UML plays a crucial role in object-oriented software development.

3.3.1 Use Case

A use case diagram offers a graphical representation of interactions among system elements. It serves as a methodology for system analysis, aiding in the identification, clarification, and organization of system requirements. These diagrams illustrate use cases and the specific roles played by actors within and around the system.

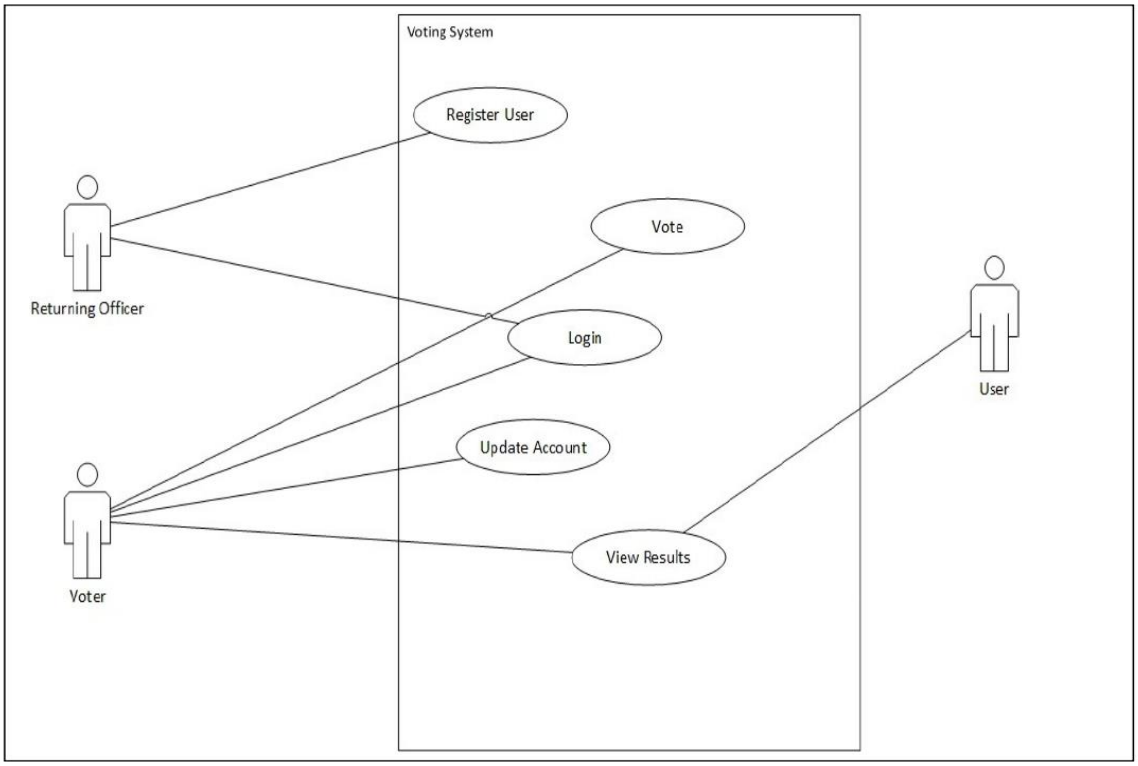

Figure 3: Use Case Diagram

3.3.2 Sequence Diagram

A sequence diagram, falling under the category of interaction diagrams, depicts how a group of objects collaboratively function, detailing the order of interactions. These diagrams are essential for software developers and business professionals, providing insights into requirements for new systems or documenting existing processes. Sequence diagrams map out interactions among various system actors, including subsystems and communication sequences.

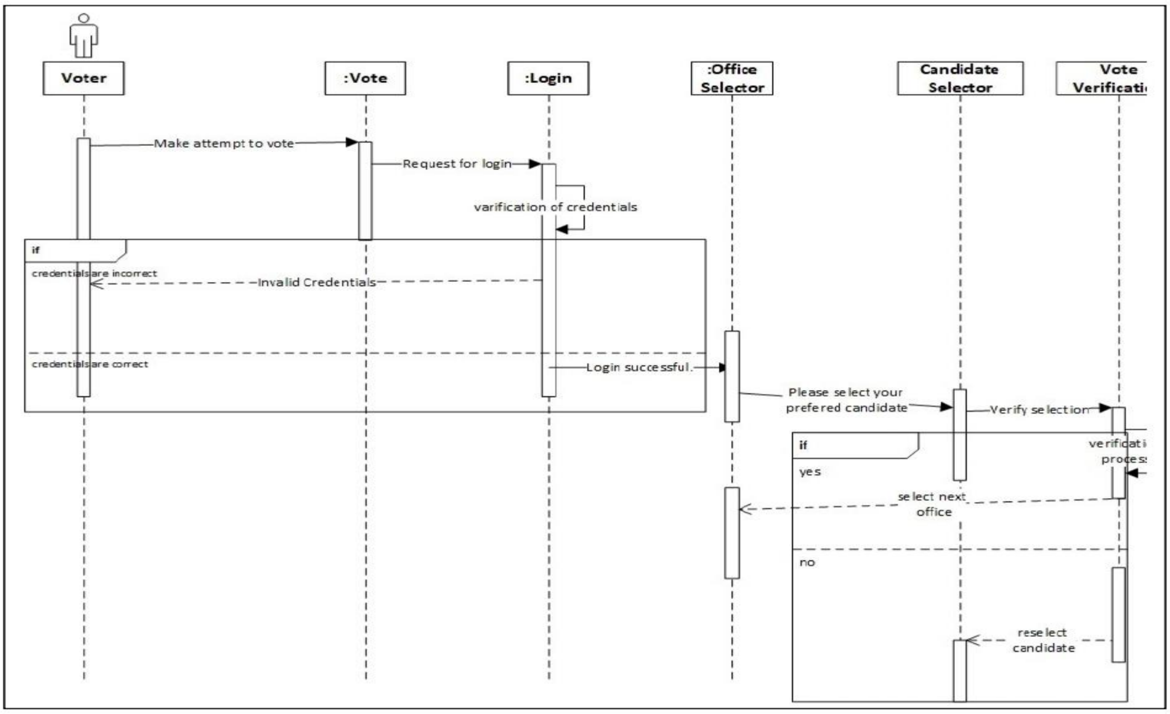

Figure 4: Sequence Diagram

3.3.3 Class Diagram

In the Unified Modeling Language (UML), a class diagram is a static structure diagram that reveals a system's structure by illustrating attributes, operations (or methods), and relationships among objects. These diagrams describe class attributes, operations, and system constraints. Class diagrams are particularly valuable for modeling object-oriented systems and are directly translatable into object-oriented languages.

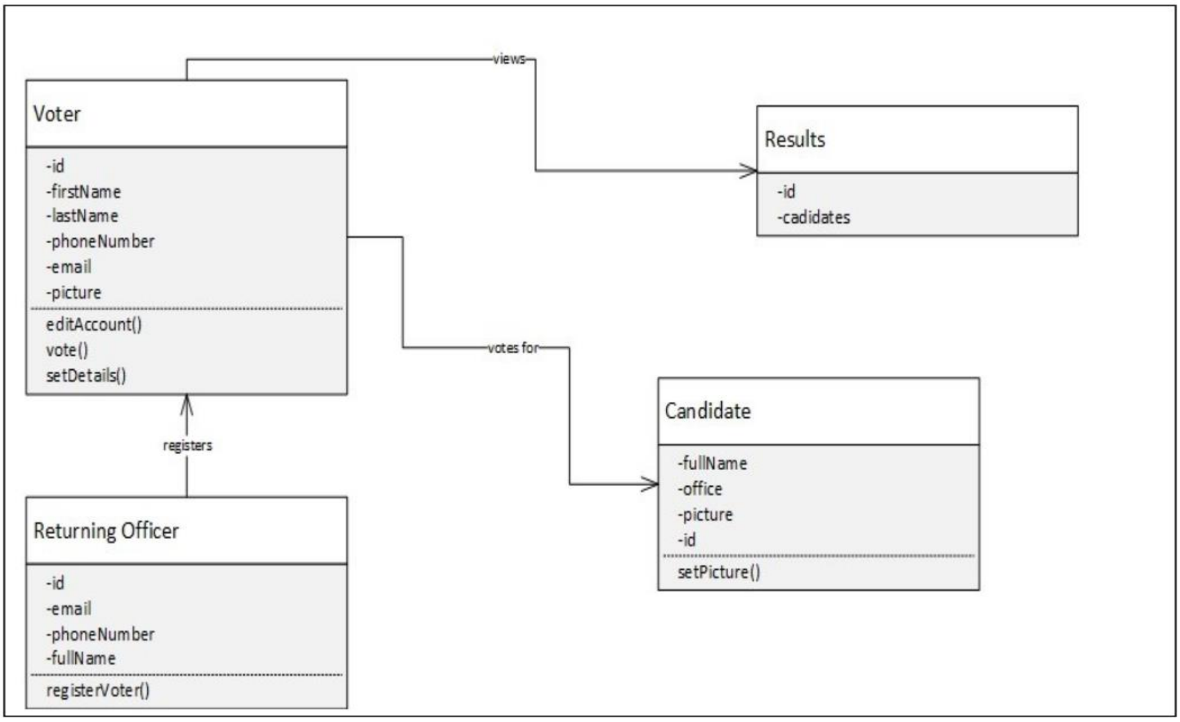

Figure 5: Class Diagram

3.3.4 Data Flow Diagram

The data-flow diagram (DFD) represents the flow of data within a process or system, typically an information system. DFDs elucidate inputs, outputs, and processes, along with data entities and their interconnections. They are integral to structured analysis modeling tools and help to visualize data flow within a system. DFDs range from simple process overviews to complex, multi-level representations, making them valuable for system analysis and design.

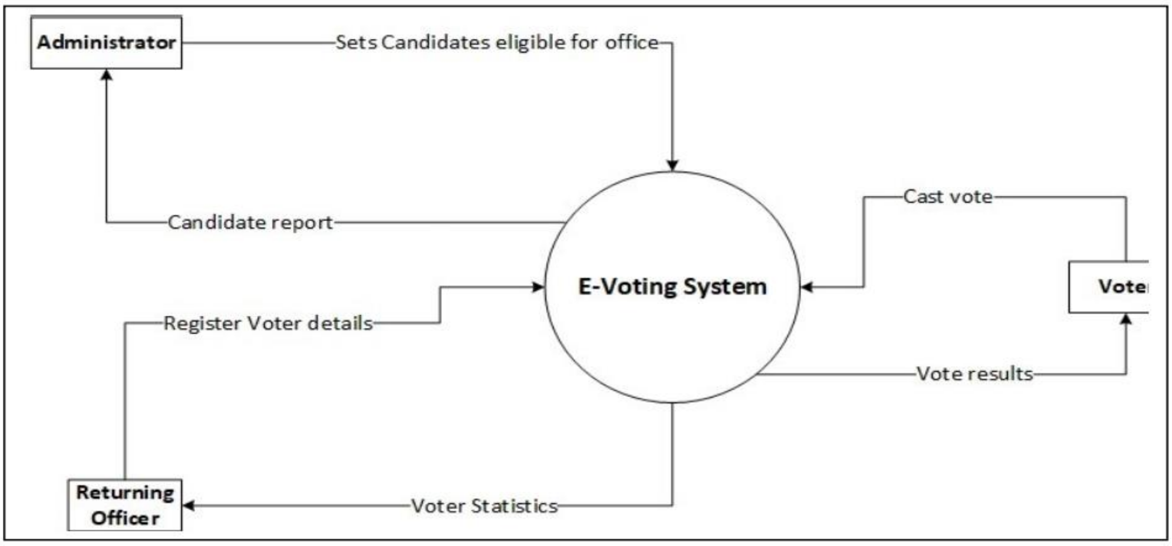

Figure 6: Context Diagram

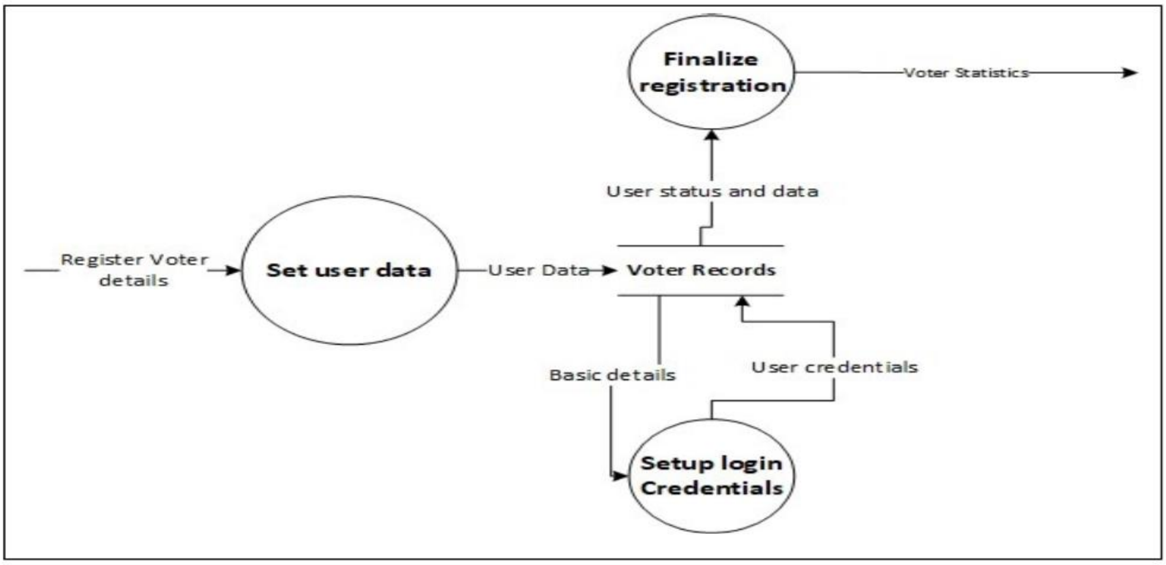

Figure 7: Data Flow Diagram

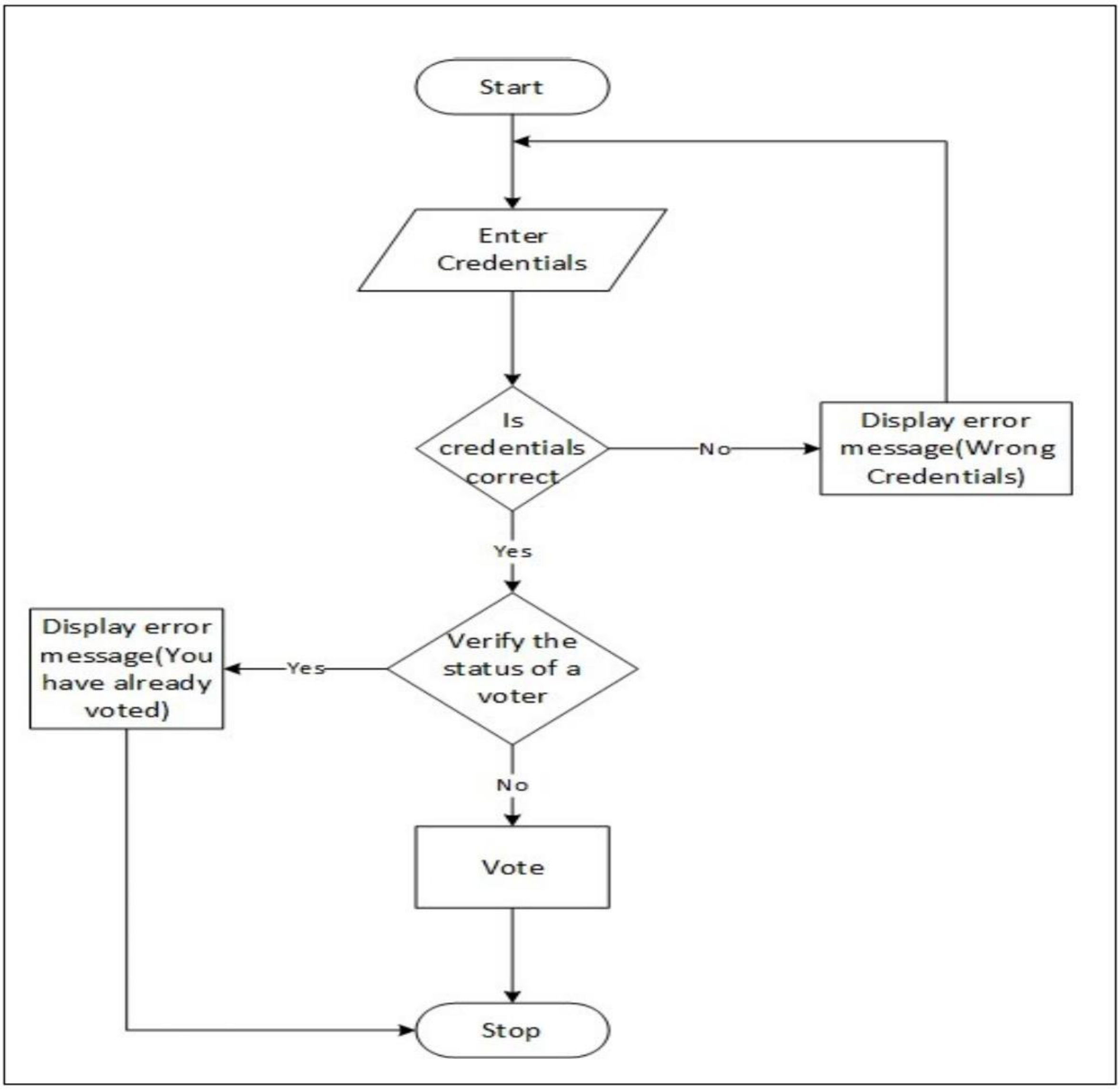

Figure 8: E-voting Systems Flowchart

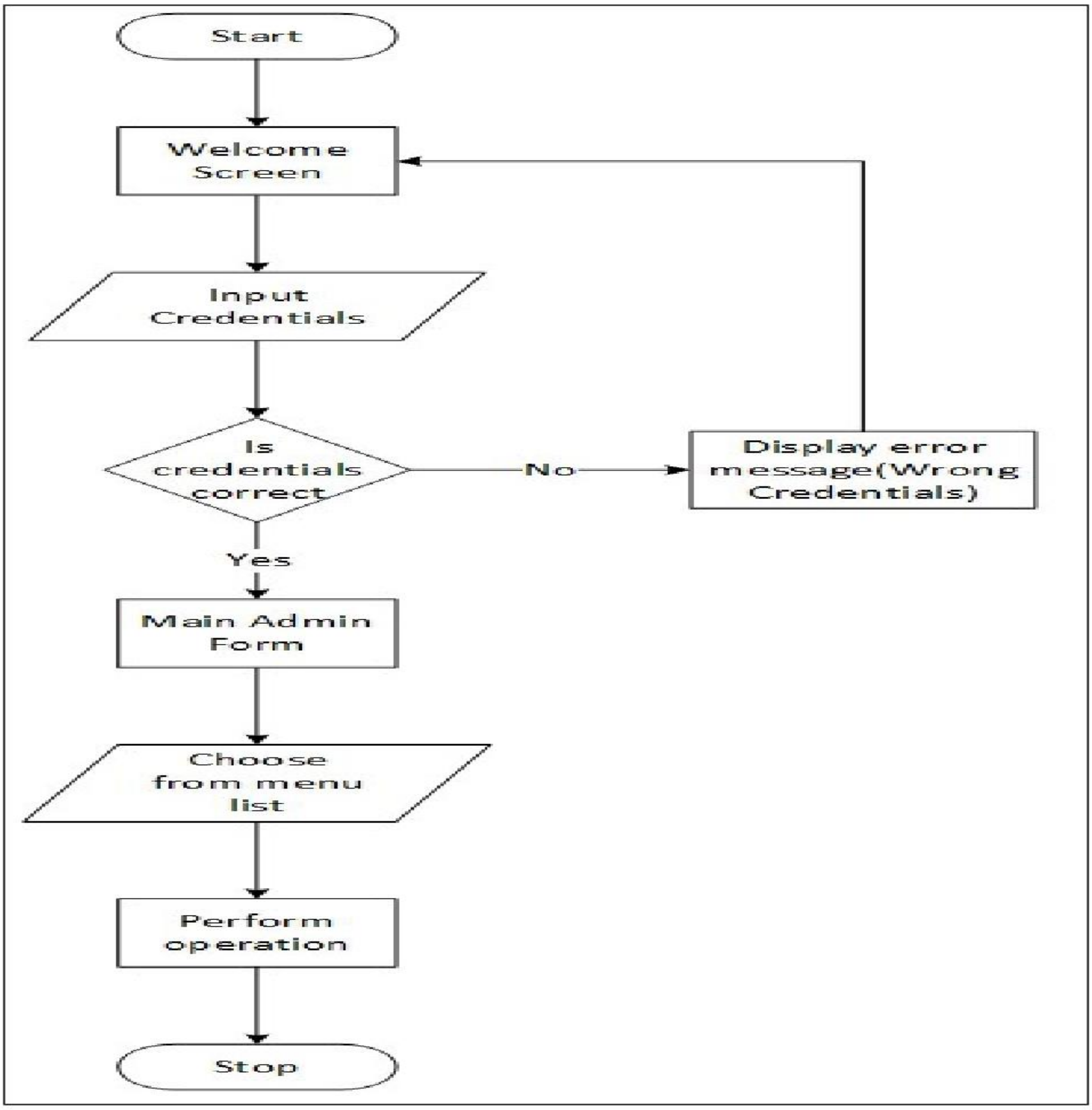

Figure 9: Flowchart Showing the Process of Voting

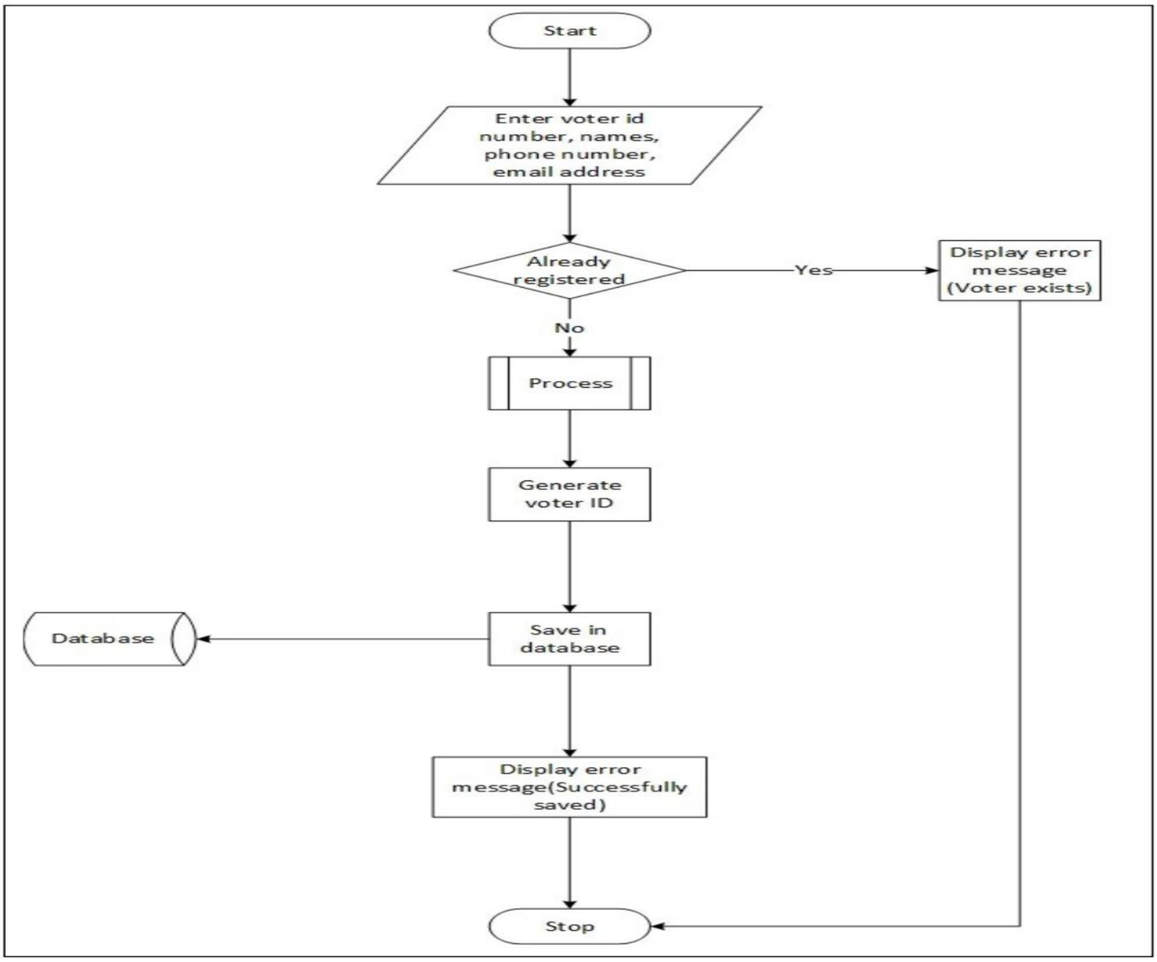

Figure 10: Register Voter Flowchart

4. System Implementation and Interfaces

In this section, we delve into the practical implementation of the E-voting System, exploring its various interfaces and functionalities.

4.1 Home Interfaces

The Home Interface serves as the initial point of contact for users upon launching the ISA app. Its primary purpose is to provide information about the Igbo Students Association. Users can access FAQs related to the association, and a menu for navigating the app is accessible via a dedicated button. While the primary focus of the project is the voting system within the app, it also doubles as an information hub for both members and non-members of the association. Advertisers can also request to feature their products on this interface for a fee.

4.2 Menu Interfaces

The Menu Interface functions as the central hub of the ISA app, presenting users with several key options:

- **Registration:** Allows returning officers to register as association members.
- **My account:** Displays the details of the currently logged-in user. If a user isn't logged in, clicking this button prompts them to log in.
- **Vote:** Navigates registered users to the voting section, where they can cast their votes.
- **Results:** Provides provisional voting results for a specific session.
- **Help:** Offers information on frequently asked questions about the Igbo Student Association and a means to contact the association.

- **Registration Interface**: This interface is accessed by clicking the "Registration" button. It enables returning officers, who possess the necessary credentials, to register new eligible voters of the association. Information collected during registration includes first and last names, ID number, email, gender, phone number, and a default password set by the returning officer. Users are required to read and accept the terms and conditions before the returning officer proceeds with registration.

- **Voter Interface:** After verifying login credentials, users are directed to the Voter Interface when attempting to cast their votes. Here, they can select their preferred candidates, starting from the president and proceeding down the list. Upon completing their vote, clicking the "Finish" button stores their choices in the database. Each office category opens a view for the voter to choose their preferred candidate from the options provided.
- **Selected Candidate Interface**: Once a category (e.g., president) is selected, this interface allows users to choose their preferred candidate for that position. Users simply select one option from the provided choices. A final confirmation is prompted to ensure the user's intent. If confirmed, the user's choice is saved, and they can continue voting for other offices. If denied, they can return to the selected preferred candidate page to make a different selection.
- **Login Interface**: Before casting a vote, users must log in to ensure that only eligible voters participate and prevent fake votes. Users enter a username and password. Only those with the correct credentials are allowed to access the voting system.
- **Contact US Interface:** In this interface, users have the option to call the association by clicking the "Call" button or send an email directly through their mail application. If users choose the email option, they are prompted to enter their full name and compose a message.
- **About Us Interface:** The About Us interface offers users relevant information about the application, their voting rights, and the governing body responsible for the app's use.
- **Results Interface**: This interface displays election results and serves as an information source for the votes cast. It presents candidate names and the number of votes they've received, with color codes explained at the bottom.
- **My Account Interface**: To access this interface, voters must log in using the information provided or given by the returning officer. They are required to change their password, ensuring it meets security requirements. Additionally, users can update their details here.

Figure 11: Menu Page

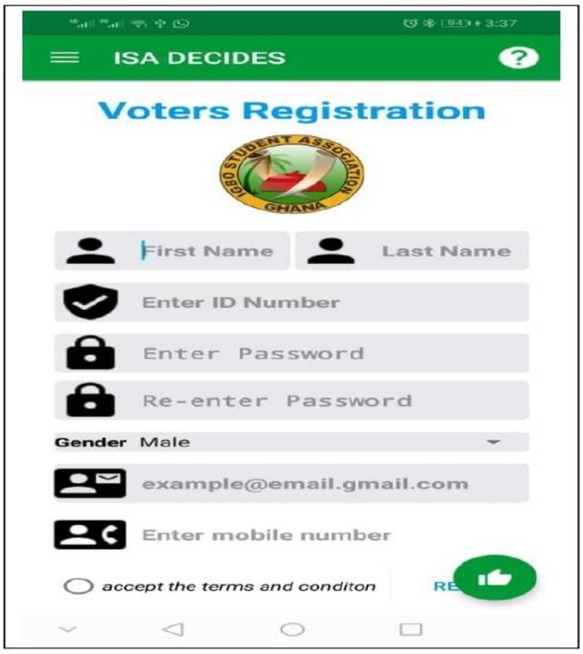

Figure 12: Voter Registration Page

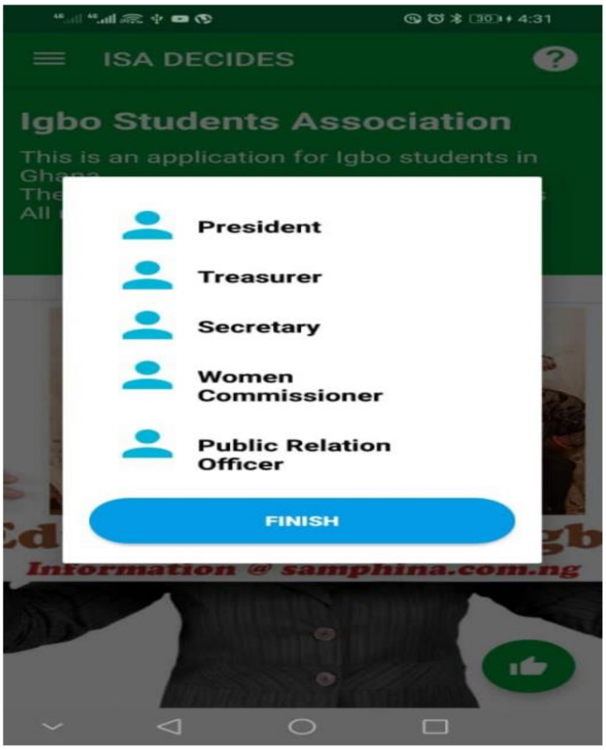

Figure 13: Candidate Voting Page

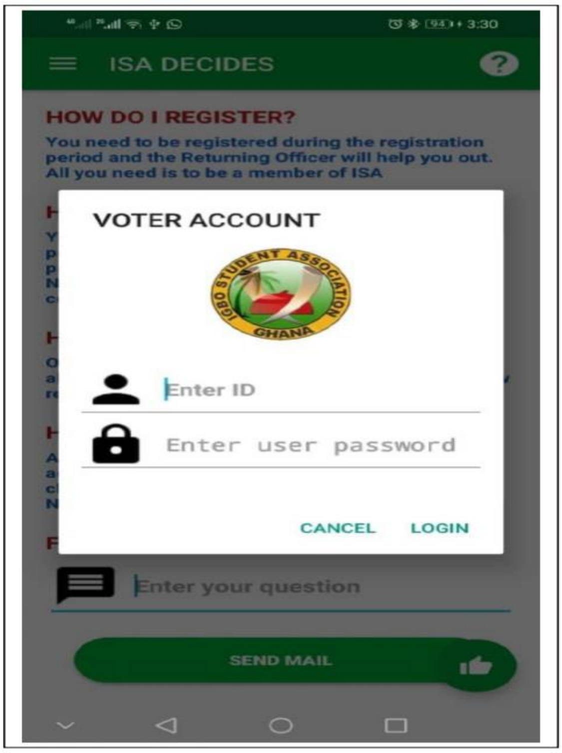

Figure 14: Login Page

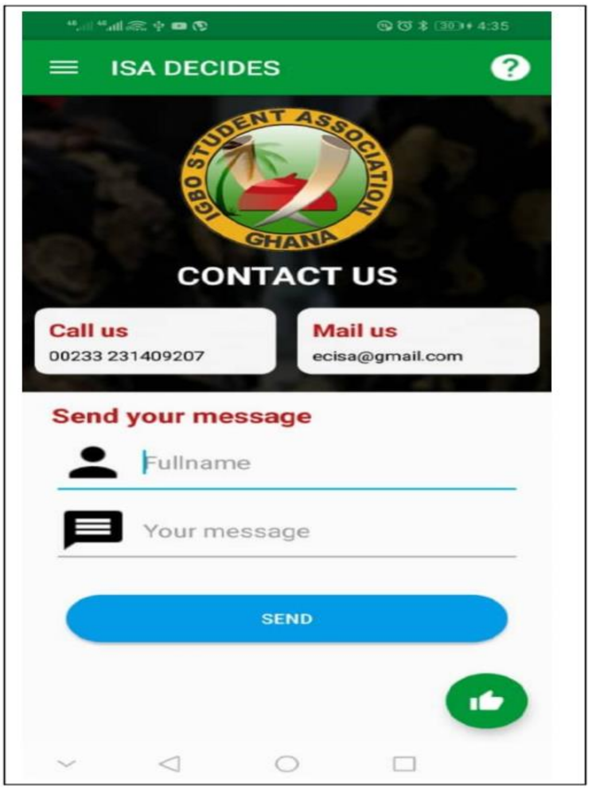

Figure 15: Contact Us Page

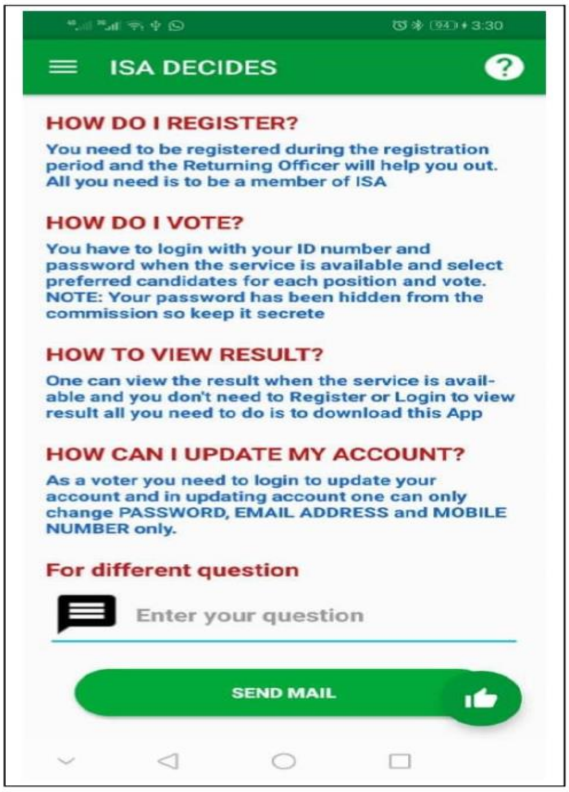

Figure 16: FAQ's Page

4.3 System Evaluation and Performance

System evaluation and testing have been conducted to ensure accuracy and correctness. User acceptance tests align the system with user requirements, and it has achieved a 98% acceptance rate. The user responses are summarized in Table 1.

The Evaluation Criterion

Criterion	Strongly Agree (8-10)	Agree (5-7)	Somewhat Agree (2-4)	Disagree (0-1)
System Accuracy	√			
Ease of use	√			
System Validation	√			
Transparency	√			
Convenience		√		
Authentication	√			
Reliability	√			
Non-coercibility	√			
Integrity	√			
Certifiability	√			
Cost-effectiveness		√		
Uniqueness	√			
Auditability	√			
Secrecy	√			

Table 1. Performance Evaluation Criterion

5.Conclusion and Future Work

The E-voting system (EVS) has received widespread endorsement in the African continent, particularly following attempts at election rigging by a few presidential candidates. Electoral fraud, or the manipulation of election results, is a prevalent issue in many African countries. Recent times, Some African countries have seen coup d'etats due to many factors: popular dissatisfaction, institutional weakness, historical precedents, authoritarian regimes, military discontent, economic crisis. One major pillars to prevent the coup d'etats is Africa is by building a strong institution to take independent decision without any political influences.

Challenges to implementing EVS at the national level in countries like Ghana include high illiteracy rates. However, its successful implementation in tertiary institutions, as demonstrated by a 98% user acceptance rate, can serve as a model for broader adoption. As these educated students graduate, they can educate the nation about the benefits of EVS over traditional systems, fostering transparency and trust in electoral systems across Africa.

Africa leaders should invest in Information Technology to develop robust e-government and e-voting applications. Collaboration between IT experts and government is crucial for timely implementation. Recent advancements in e-government in Ghana exemplify progress in this direction. It is advisable to implement e-voting systems within half a decade to ensure transparent, auditable, and trustworthy electoral processes in Africa.

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