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V-Authenticate: Voice Authentication System for Electorates Living with Disability

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Abstract: Every ethnic, religious, and gender communities have electorates living with disability. They represent approximately 0.15 percent of the world's population roughly one out of every seven. When appropriate mechanism is not in place for such large volume of populace to fully participate in the electoral process, it deters democracy from giving this subset of populace a choice from how they wish to be governed. Electorate voice biometric modality could serve as credential to recognize legitimate voters. The voice recognition process relies on features influenced by the physical attribute of vocal tract and the behavioral features of the individual. Voice biometrics differs from other biometric techniques, in that speech samples are captured dynamically over a period of time. Incorporating technologies like the voice recognition system for authentication for the disabled is a huge step in increasing trust and inclusive participation in the democratic process. In this paper, we present V-authenticate, a voice authentication system to address the issue of valid voter's recognition and verification for the disabled electorate using their voice trait as biometric input parameter. The developed system was evaluated objectively using Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) qualitative metrics. The result of analysis system performance showed an average MSE value of 0.7 and PSNR was 42.9214 decibel showing the consistency of the applied algorithms to authenticate valid electorate living with disability. The system can be adapted by voting authority to enable electorate living with disability to participate in future electronic democratic decision making.

***Keywords*:** Voice; Security; Authentication; Voting; Democracy; Inclusion; Disability

I. INTRODUCTION

Democratic governance provides citizens the liberty to choose their leaders by means of election. One of the critical pillars to democratic process is voting (Okediran and Ganiyu, 2015). Voting provides individuals with a voice to influence decisions that affect their lives. However, electorates with disabilities have often been discriminated against in this context. In December 2006, historical response to the exclusion of people with disabilities from social and political processes by the United Nations (UN) General Assembly gave birth to the adoption of Convention on the Rights of Persons with Disabilities (CRPD) report (International Foundation for Electoral Systems, 2012). The UNCRPD report is an international human rights treaty, which promotes, protects, and ensures the fundamental human rights by persons with disabilities, particularly to public participation (International Foundation for Electoral Systems, 2014).

According to Article 1 of the UNCRPD treaty, the rights apply to everyone with a disability, including *"those who have long term physical, mental, intellectual or sensory impairments"*. Article 29 of the treaty focuses on participation in political life. It ensures *"that persons with disabilities can effectively and fully participate in political and public life on an equal basis with others, directly or through freely chosen representatives, including the right and opportunity for persons with disabilities to vote and be elected"* (International Foundation for Electoral Systems, 2012; National Democratic Institute, 2012). As of August 2016, the UNCRPD has been signed and ratified by 160 countries. Of these, 23 African countries ratified the convention and protocol, and 16 African countries including Nigeria ratified the convention (Virendrakumar *et al.*, 2018a).The convention seeks to legislate laws and policies existing in these countries to ensure the participation of people with disabilities in general elections. Laws in countries such as Guinea, Mali, Nigeria, Ghana, Liberia, Burundi, Democratic Republic of Congo and Cote D'Ivoire allows voters with disabilities to request the assistance of a family member or a friend to cast their vote (Virendrakumar *et al.*, 2018a). Some African countries referred to the protection of human rights for the populace, while fifteen countries specifically provided for the political participation of people with disabilities (Virendrakumar *et al.,* 2018b).

Overall, the UNCRPD document proclaimed equal opportunities for people with disabilities to exercise their franchise and referred to specific adjustments, mainly personal assistance, accessible communication and prioritization at the polling stations (Virendrakumar *et al.,* 2018a; Virendrakumar *et al.,* 2018b). In Nigeria for instance, the Independent National Electoral Commission's procedures allow people with disabilities in a targeted manner through priority access to polling units (especially visible pregnant women) to jump the queue in polling units when voting or registering to vote, use Braille Guide glass for visually impaired/blind registered voters and complete a special form(EC40H) (INEC, 2019).

According to National Population Commission, people living with disability in Nigeria is estimated to no fewer than 19 million (Premium Times, 2018). This margin has increased by an approximate number of 25 million (Haruna, 2017). The total adoption of People Living with Disability (PWD) framework by Independent National Electoral Commission (INEC) will ensure the voting process is more accessible to PWDs (International Republican Institute, 2018). Also, the legislative amendment of the Electoral Act by the Nigerian Senate empowering the INEC to introduce and implement any e-voting technology it deems suitable (Policy and Legal Advocacy Centre (PLAC), 2017; Verified Voting Foundation, 2017) will further enable improved participation by PWD.

Electronic voting characteristically is a multi-disciplinary subject studied by experts of different fields like engineering, cryptography, politics, law, economics and social sciences (Okediran *et al.,* 2011; Olaniyi *et al.,* 2015).Mostly e-voting is a challenging topic in cryptography and this arises primarily from the need to achieve voter anonymity from casted ballot, ensuring voter privacy without any violation and ensuring only eligible voters' votes have been counted (Cetinkaya & Cetinkaya, 2007). Another great challenge is the need for electronic voting system to enable disabled people in the sense that there is a critical need for the provision of a system to enable election participation by the disabled. The UNCRPD responds to this circumstance by providing a holistic solution to this need. Article 29 addresses the design and implementation of an electoral process that is non-discriminatory, while also requiring states to provide voters with disability-related accommodations and other facilitative measures to enable their equal right to vote (Virendrakumar *et al.,* 2018b). A number of secure electronic voting systems have been developed particularly for developing countries ecosystems using different techniques in the last decade (Enokela & Osuagwu, 2011, Aranuwa and Oriola, 2012; Abdulhamid *et al.*, 2013, Okediran and Ganiyu 2015; Olaniyi, *et al.,* 2016,Oke *et al*., 2017, Oke *et al.,* 2019). However, little attention has been given to design considerations to electorates with disability despite the fact that one out of every seven and no fewer than 25 million Nigerians are living with disabilities.

In this paper, we present V-authenticate, a voice recognition and verification system to address the issue of authentication for the disabled electorate by taking their voice as a measurable biometric trait. The rationale for the selection of voice trait for authentication is based on the fact that voice contains both physiological and behavioral factors unique to an individual. This measurable trait is difficult to duplicate since voice qualities are measured ranging from spectral magnitudes, dialect, style of speaking to pitch and format frequencies. Attempts to impersonate a voice or provide voice recordings to compromise authentication would fail due to the distinctive details of the voiceprint used for comparison and validation of valid voters (Authentify Inc, 2016). The remaining section of the paper is organized into three. Section II presents the system design methodology for the proposed system; Section III presents the results and discussions while Section IV concludes and opens scope for future research endeavors.

II. SYSTEM DESIGN METHODOLOGY

A. System Design Specification

In order to achieve a complete and functional system, the design and development of the system must be elucidated.

Figure 1 is a representation of the system architecture of the e-voting system showing the three phases of the electioneering process for the PWD: Pre-Election phase, Election phase and the Post-Election phase. It also includes the front and the back tier of the system.

This aspect involves the prerequisites essential for the accomplishment of the system based on the architectural design view for the purpose of implementation. The following are the design requirement specifications for each of the blocks in Figure 1:

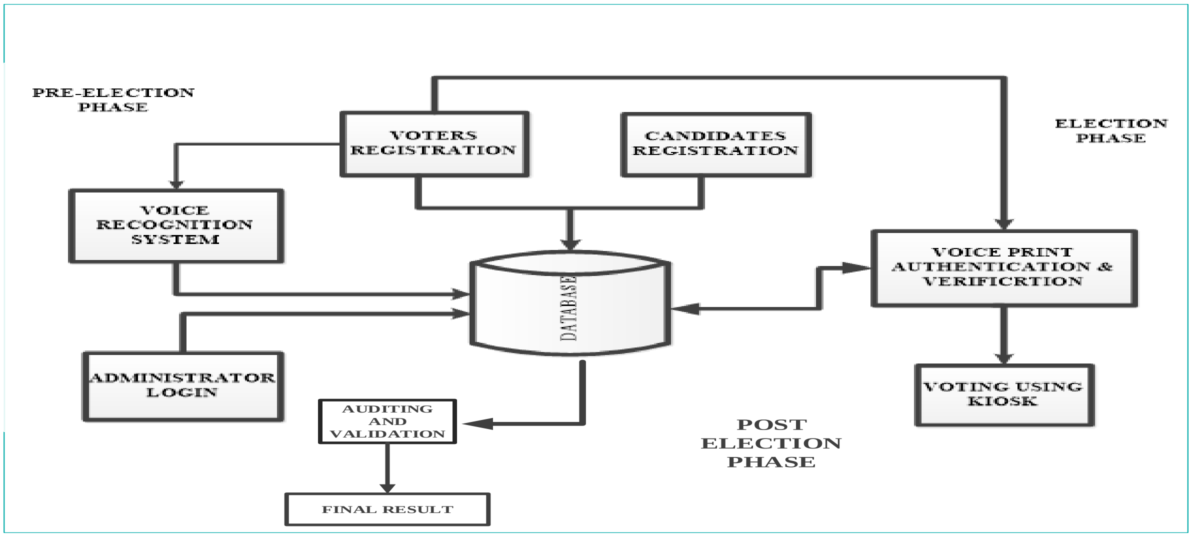

Figure 1: V-Authenticate System Architecture

- **Voice Recognition System:** The voice recognition system is a major part of the V-Authenticate-Franchising system for PWD. This system is responsible for the authentication and verification of voters as well as their votes. During the enrollment (registration) phase, voters register their personal information like age, date of birth, and address to the electoral official for record purposes, then they are required to give an input of their voice print (i.e. they speak into the microphone for voice print capture). Base level identification is done by assigning to every voter, a unique user identification number to be used in the identification of voters before the biometric capture.
- **Voting system:** The voting system is empowered with the voting software application that gives the interface of the voting process. It has a user friendly interface that enables the administrator/electoral official to easily conduct the registration for the individual voters. The voting system and the voice recognition system are heavily interwoven in the sense that they go hand in hand in their operations.
- **Database:** The database contains all the information provided by both the voter and the candidate. It guarantees the authorization of the voter by interfacing with the voting system application.

The proposed system by Figure 1 is divided into three different interwoven stages which are pre-election, election and post-election phases as mentioned earlier. The following are activities that are required to take place at each of the phases of the electioneering process:

- **Pre-election Phase**: This is the initial stage of the election process where the contestants, parties and the voters (PWD) are registered by the administrator during the enrollment phase. Details about the contestants are being inputted into the system and stored in the database; such information can be edited by the administrator if the need arises. During the voter's enrollment, a unique user ID that identifies to them alone is issued to the voters. Their voice prints are taken and stored in the database in anticipation for the Election Day. It is to importantly note that no two voters must have the same user ID and as such no two voters can have the same voice print because it is biometric.
- **Election Phase**: This is the stage of the electioneering process whereby the disabled voters come to the polling station to cast their votes, but first, they are authenticated by the system by providing their user ID and also their voice, meanwhile taking into cognizance that it has to be the same phrase uttered during the enrollment that is also required for the authentication process. During enrollment, speech sample is acquired in a controlled and supervised manner from the voter. The speaker recognition system has to process the speech signal in order to extract speaker discriminatory information from it to form the speaker model. During verification of the speech sample acquired from the user, the recognition system extract the features from the sample acquired and compare it against the models already stored beforehand for pattern matching/classification. Only eligible voters are allowed to vote as authentication and verification of identity is done before the voting takes place.
- **Post-Election Phase**: This is the final stage of the electioneering process, after the votes have been casted, they are being recorded and stored in the database for further processing. At this stage of the election

process, only the administrator has the rights to access the database. The votes are computed, validated and the results are generated for public declaration.

B. System Hardware and Software Design Specification

Hardware Requirement: These are the components part of the system that can be seen and touched. The major hardware component of the system is an external Universal serial bus (USB) Microphone, the kinobo Rikuto conference style USB microphone for voice input and recording purposes. It has captures frequency with a range of 20 Hz-20000Hz

Figure 2: Akiro Kinobo USB Microphone

Software Design Requirement: Based on the perspective of software engineering. The system is being stratified as stipulated as follows:

- **Voice Recognition Authentication and Verification:** In voice biometrics works disabled person's speech is digitized to produce a stored model voice print, or template. The voice digitization reduces each spoken word to segments composed of numerous dominant frequencies referred to as formants. Each segment has several tones that can be reconfigured in a digital format. The tones collectively identify the speaker's unique voice print which are stored in database. The voice recognition and verification involves three major steps which include:
  - i. Pre-processing of captured speech
  - ii. Feature extraction using Mel-Frequency Cepstral Coefficients (MFCC) Algorithm
  - iii. Feature Classification using Dynamic Time Warping (DTW)

Speaker recognition system consists of two main stages, the enrolment stage and the verification stage. These phases involve three main parts as shown in Figure 3. From Figure 3, at the time of voice enrollment, the voice sample is acquired in a controlled and supervised manner from the voter. The speaker recognition system has to process the speech signal in order to extract speaker discriminatory information from it.

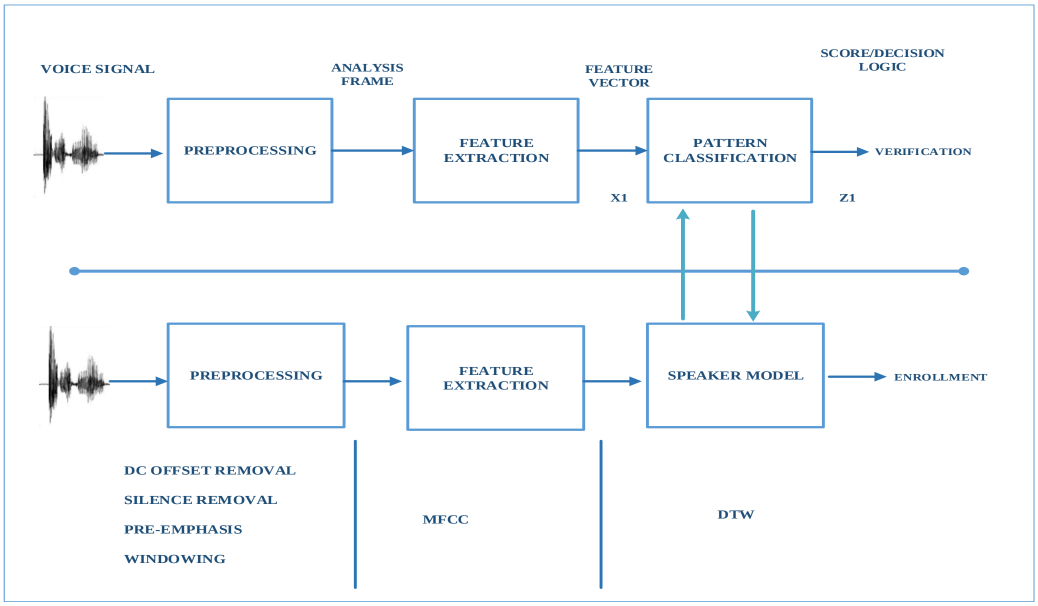

Figure 3: Representation of the voice recognition system

C. Pre-processing

Speech data performs in a discrete-time speech signal because such data are recorded by sampling the input. Therefore, some pre-processing techniques are required to make the discrete-time speech signal more flexible for further processes. There are four pre-processing techniques that come before feature extraction. These include DC offset removal, silence removal, pre-emphasis and windowing.

- DC Offset Removal: Speech data are discrete-time speech signal; it often carries some redundant constant offset called DC offset. This DC offset will affect quality of the information extracted from the speech signal. Consequently, we calculate the average value of the speech signal and subtracting this from DC offset from the original speech signal.
- Silence Removal: This process is performed in order to remove silence periods from the speech containing silence frames. So, the signal becomes more compact as shown in the Figure 3. Silence frames are audio frames of background noise with a low energy level with respect to voice segments.
- Pre-emphasizing: Pre-emphasis is a technique used in speech processing to enhance high frequencies of the signal. The main purpose of pre-emphasizing is to spectrally flatten the speech signal that is to increase the relative energy of its high-frequency spectrum.
- Windowing: This step requires processing the window of each individual frame in order to minimize the signal discontinuities at the beginning and end of each frame. A windowing function is used on each frame to smooth the signal and make it more amendable for spectral analysis. The concept here is to minimize the spectral distortion by using the window to taper the signal to zero at the beginning and end of each frame. If the window is defined as Y_1 (n), where n is the number of samples in each frame, then the result of windowing is the signal

$$\mathbf{Y_1(n) = x\,(n)w(n), \qquad 0 \leq n \leq N-1} \tag{1}$$

Typically, the Hamming Window is used, which is of the form

$$w(n) = 0.54 - 0.46\cos[2\pi n/N-1], \quad 0 \leq n \leq N-1 \tag{2}$$

D. Feature Extraction

The voice feature was extracted using MFCC algorithm. Mel-frequency is the measure of the human perception of the frequency content of speech signals on the “Mel-scale”. Mel-Frequency Cepstrum (MFC) stands for the power spectrum of the speech, based on a linear cosine transform of a log power spectrum, computed on the non-linear Mel-frequency. The MFCC features are obtained by taking the log of the outputs of a Mel-frequency filter bank, which is subsequently subjected to cepstrum analysis (Thakur, 2015)

The final MFCC feature vectors are obtained by retaining about 12-15 lowest Discrete Cosine Transform (DCT) coefficients. Each vector is independent of each other and ordering information is lost. The MFCCs are, therefore, the coefficients that collectively make up the MFC. The frequency bands in the MFC are equally spaced and from research findings in the psychophysical field, it has been established that the Mel scale approximates the auditory system of humans better than a linearly spaced frequency band. Melfrequency warping of the spectrum gives emphasis on low frequencies that are more important for speech perception by humans. The computational components of the MFCC algorithm are captured in Figure 4 (Thakur, 2015):

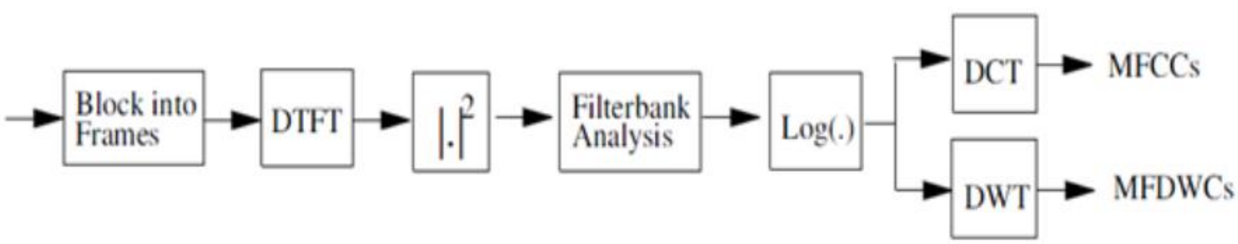

Figure 4: Extraction voice feature Using MFCC (Chang, 2012)

E. Feature Classification

The pattern classification task of speaker recognition involves computing a match score (a measure of the similarity of the input feature vectors) to some model. Speaker models are constructed from the features extracted from the speech signal. To enroll users into the system, a model of the voice, based on the extracted features, is generated and stored in a voting database. To authenticate a user/voter, the matching algorithm compares/scores the incoming speech signal with the model of the claimed user. The technique used for the pattern classification from Figure 3 is the Dynamic Time Warping (DTW).

Dynamic time warping is an algorithm for measuring similarity between two sequences which may vary in time or speed. DTW is an algorithm that focuses on matching two sequences of feature vectors by repetitively shrinking or expanding the time axis till an exact match is obtained between the two sequences. It is generally used to calculate the distance between the two-time series that vary in time. A real time application of DTW in the voice recognition is that, it should be able to recognize the user's voice even when spoken at different speeds. In order to check the similarity between two voice signals or the time series are warped non-linearly.

F. System Performance Evaluation Measures

Objective evaluation tests: The objective comparison of single channel speech of the voters captured was carried by evaluating the speech signals (original and processed speech) with Mean Square Error (MSE), and Peak Signal to Noise Ratio (PSNR) performance evaluation metrics. These metrics were computed based on mathematical comparison of the original and processed speech signals.

- **Peak Signal to Noise Ratio (PSNR):** This is used to estimate the difference between the recorded and the processed speech and is a function of the Mean Square Error (MSE). It is a ratio of the quality of the recorded voice sample against the processed voice sample calculated in decibels. The higher the PSNR (in equation 3) of the comparison, the better the analysis.

$$\text{PSNR} = 10 \log_{10} = R^2 \div \text{MSE} \tag{3}$$

Where R is length of the reconstructed signal

- **Mean Square Error (MSE):** This is an error metrics used to represent the cumulative square error between the original voice signal and the processed voice signal. The lower the value of the MSE, the lower the error rate between the samples which shows proper processing of the signal. It is calculated using the following relation in equation 4:

$$MSE = \frac{1}{4MN} \sum_{i=1}^{2M} \sum_{j=1}^{2N} \left(C_{ij} - S_{ij}\right)^2 \tag{4}$$

Generally, PSNR values below 30db signifies a fairly low quality. While, the value of MSE decreases when the two signals are similar to each other. A better quality signal would strive for 40db and above.

III. RESULTS AND DISCUSSION

The software prototype for the V-authenticate was developed Using MATLAB Graphical User Interface(GUI) called GUIDE, Figures 5, 6, 7,and 8 show the developed interface of the voting system which allows electorates with disability to franchise their choice in democratic governance.

Figure 5 shows the main voting platform while figure 6 depicts software platform for registration and eligible voter voice samples. The registration procedure is commenced for the proper documentation of the information about the voter in Figure 6.

Figure 7 shows the verification page which comes after the enrollment is done in figure 6. Here, the voter provides his/her user ID and the administrator loads it and the voter is then required to repeat the same phrase that was used during the enrollment stage for verification. If the user ID is correct, then the voter is allowed to record their voice for verification of identity after which they are redirected to the voting page to cast their votes.

In Figure 8, there is an automatic voice prompt that instructs the voter of the next step to be taken. The voter makes a choice via voice instruction and the vote is casted for voters preferred choice on the voting interface. Using the metrics outlined in Section III. The result of the tested developed system is shown in Table 1. Table 1 shows the voice sample of six voters' audio files evaluation with the various sizes, bit rates, vote size, and the audio sample size as well. It shows the voice sample analysis after evaluating their Mean Square Error (MSE) and Peak Signal to Noise Ratio in MATLAB software toolbox.

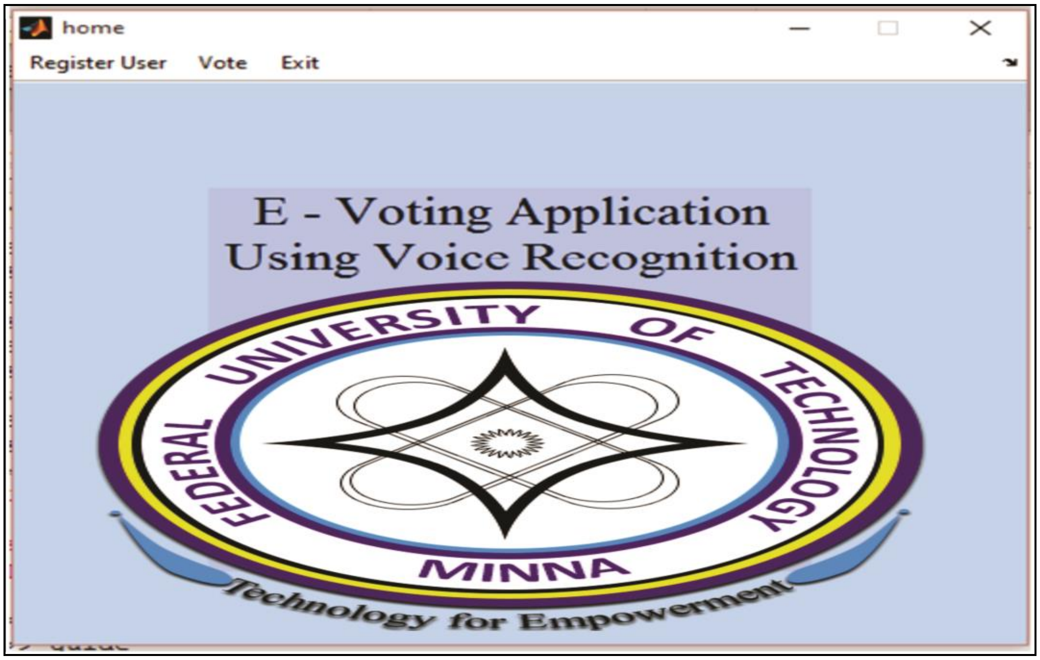

Figure 5: Electronic Voting System Home Page

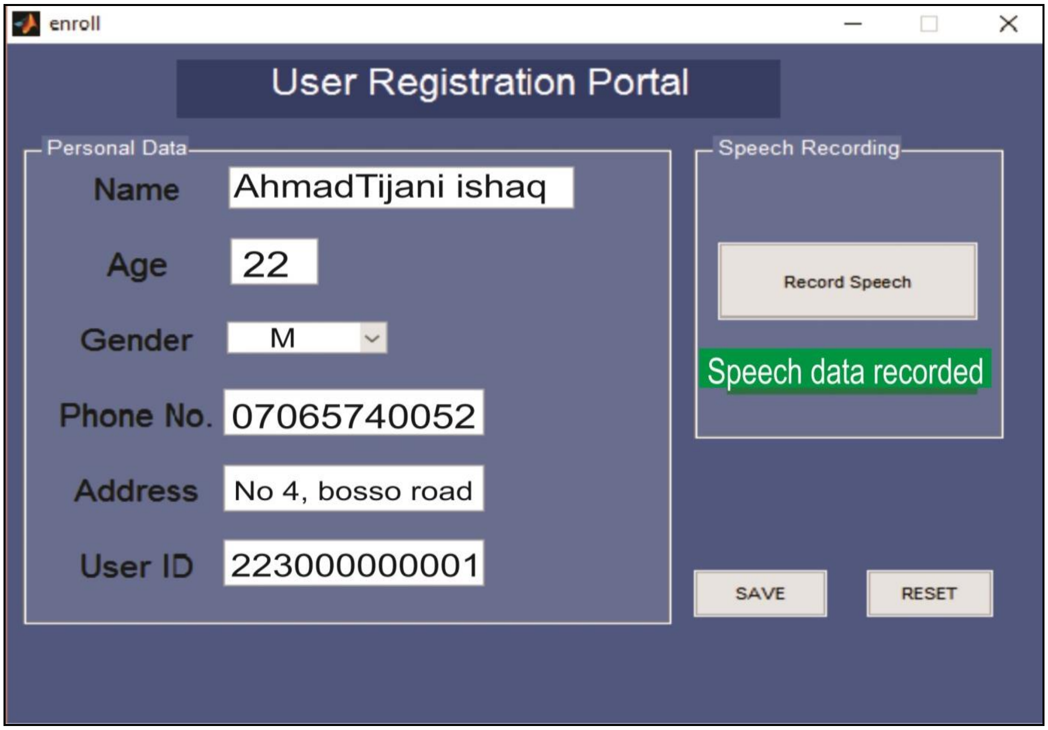

Figure 6: The voter enrollment page using Voice print input

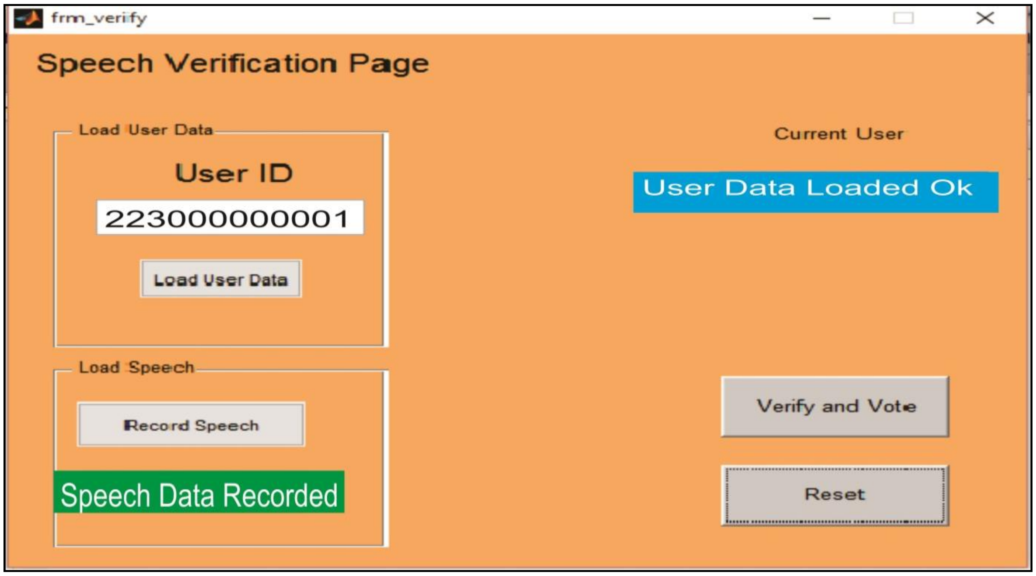

Figure 7: Voter Voice Verification page

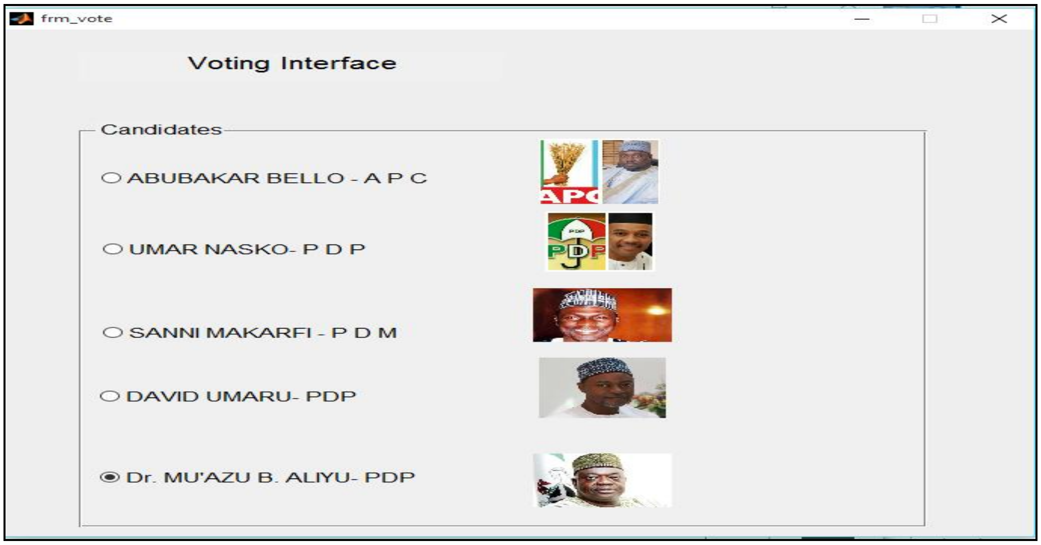

Figure 8: The voting interface

Table 1: MSE and PSNR of the Sampled Audio Voice Files

Voters Audio Voice File	Audio size (KB)	Bit Rate (Kbps)	Vote Size (kb)	MSE (db)	PSNR (db)
Tunde	20	120	1.62	0.312	41.5478
Saleem	29	135	1.81	1.002	38.2577
Taofeek	45	163	2.30	0.541	45.3698
Adam	38	139	2.21	0.126	56.3688
Ibrahim	46	143	2.36	1.320	40.2365
Niyi	27	134	1.75	1.112	35.7482

From Table 1, the average value of MSE value was 0.7 and PSNR was 42.9214 decibel. By the premises provided in Section II, PSNR values below 30db signifies a fairly low quality. While, the value of MSE decreases when the two signals are similar to each other. A better quality signal would strive for 40db above. It is clear from the results of performance measure in Table 1 (with computed average value of MSE and PSNR values) that V-authenticate- e-voting authentication system can be adapted to enable PWD to participate in future democratic decision making since the value is quantitatively higher than the standard benchmark proving the efficiency and effectiveness of the techniques adopted in Section II.

IV. CONCLUSION AND RECOMMENDATIONS

This work has successfully shown significant improvement on the existing secure voting authentication systems by focusing on design considerations for the disabled persons via voice biometric recognition. This work includes the three phases of the electioneering processes. The voice recognition system takes care of the authentication and verification of PWD voters. The signal analysis of the voice signal was accomplished by using MFCC technique on voice spectrum factors. This represents the exact vocal system for stored words and provide a high level of perception of the human voice and a better representation of the signal. This accounts for a higher resolution in the performance of recognition. Having tested and evaluated the developed system, it can be inferred or concluded that the system could be adopted by voting authority, like INEC, as part of measures to fully embrace people living with Disability (PWD) framework to ensure the voting process is more accessible to PWDs.

However, our contribution in this work principally authenticates voters based on ***"Isolated Word Recognition"*** metaphor. It is recommended the work can be extended to ***"Continuous Word Recognition"*** and ultimately create a Language Independent Recognition System capable of making the developed system more robust in terms of performance. Also, Statistical Models like Hidden Markov Models and Gaussian Mixture Models as well as learning models like Neural Networks can be incorporated in this direction to improve quality of voice signals required to verify valid voters with disability. This would make the system much tolerant to noise variations and associated residues and hence make it less error prone. Other open issues that can be looked into are:

- Addition of a cryptographic technique for digital vote signature to increase integrity of the votes.
- A multimodal biometrics for multifactor authentications for subjects in the same domain of application.

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