

Architecture of a Low Cost Electronic Voting Machine Suitable for Deployment in Developing Countries.

Jonathan A. Enokela, Ph.D^{1*} and Charles C. Osuagwu, Ph.D²

¹Department of Electrical Engineering, University of Agriculture, PMB 2373, Makurdi, Nigeria.

²Department of Electronic Engineering, University of Nigeria, Nsukka, Nigeria.

*E-mail: jenokela@yahoo.com

ABSTRACT

Electronic voting machines are becoming increasingly popular in various democracies around the world because of the realization that their deployment will lead to generally better elections. Due to the fact that problems with elections vary from one country to another, a global electronic voting machine may not be realizable. Environmental and attitudinal factors contribute to the suitability of a voting system for a particular country. Such factors are discussed and the configuration of a machine that could be used to solve the problems in developing countries is exhaustively analyzed. A prototype of the machine that has been developed performs satisfactorily and solves virtually all the problems highlighted.

(Keywords: electronic voting machine, election, democracy)

INTRODUCTION

Elections constitute one of the most important processes in a modern democracy [21]. It is through this process that leaders in the executive and legislative arms of a democratic government are brought into power. Elections represent a direct measure of the feelings of the people about a government or political leaders. It is thus important that elections be conducted in a manner that shows a high degree of confidence and transparency in the process [22]. As a matter of fact the quality of a democratic government is directly related to the quality of election that brought that government to power.

Democratic countries among the developing nations have organized several general elections. These elections have generally been rigged and have left poor impressions among the populace

with the results that confidence in the electoral process has plummeted to a very low level [13]. The poor handling of elections have also led to instability in governments [15], [16]. Most of the elections in these countries have been conducted using the means of paper ballots and ballot box. Politicians have devised various means of defeating this method of conducting elections. Indeed it is the view of many election administrators that as long as the ballot box and paper ballot form part of the election system, the possibility of tampering with both by criminally-minded people cannot be ruled out [15].

At the moment the best possible alternative method of conducting elections that will give much more credible results is the use of the electronic voting system [19], [22]. This realization has led many democracies to begin to shift from the traditional method of conducting elections using the ballot box and papers to this modern way of conducting elections [3], [4], [6], and [12]. Many laws and problems that affect the administration and outcome of elections are specific to the local election environment. The peculiar nature of these problems implies that voting machines must be developed to solve problems that are inherent in the particular environment [18]. Thus a global electronic voting machine may not be realizable and a machine developed for a particular environment may not solve all the problems of another environment but indeed may cause usability problems in other environments [2], [17].

PROBLEMS WITH ELECTIONS IN DEVELOPING COUNTRIES

The problems with elections in developing countries can be illustrated by those of Nigeria and Zimbabwe. Elections in these two countries have drawn the most virulent criticisms from their

citizens and the international community at large [1], [11]. The methods that have been used to rig elections in these countries can be classified as shown in Table 1.

Violence

Many notable politicians have used violence to distort election results [1]. Thugs are freely used in elections to harass and intimidate voters of the opposing parties. These thugs have been known to burn not only properties and ballot papers but even human beings. They have been used to shoot opponents at will and they have invalidated ballot papers by pouring indelible ink into ballot boxes in order to blot out fingerprint marks. Thugs have been used to hijack ballot boxes which they stuffed with ballot papers and later returned to the collating centre to be counted as valid votes.

Under-aged Voting

Children whose ages were below the official voting age have been known to cast votes in elections. This has resulted in the distortion of the figure of the voting population.

Multiple Registrations of Voters

It is at the point of voter's registrations that politicians begin to manipulate the election system. Truckloads of supporters of political parties are sponsored to register in many locations. The possession of multiple voters' cards makes it possible for a voter to cast more than one vote. Indeed voters have been known to move from one polling station to another to perform multiple voting during elections [5]. Multiple registrations also deny the opponents access to polling stations on Election Day.

Stuffing of Ballot Boxes/multiple Voting

Voters have been known to use the secrecy of the polling booth to dump pre thumb-printed ballot papers into the ballot box. The method of displaying ballot boxes in the open violates the fundamental requirement of secrecy but even this has not deterred the politicians as other methods have been devised to stuff the ballot box with ballot papers. Ballot boxes have been detoured to

the homes and farms of politicians where thugs thumb printed ballot papers and stuffed them into the boxes at their leisure. The thugs are now much bolder: they snatch ballot boxes from polling stations and stuff them with ballot papers. These ballot boxes which were ostensibly snatched by violent means were still submitted to the collating centre and their contents were accepted. This situation is possible because the presiding officer has already been bribed to cooperate with the thugs.

Individual roving voters cast multiple votes during an election. After the cast of the first vote they wipe off the ink mark on their thumbs and because they have acquired more than one voters' card they move from place to place to cast more votes [5].

Inflation of Votes Cast

In Nigeria the Electoral Act [7] specifies that no polling station should have more than 500 voters. Yet at the collating centres results were accepted which showed that a polling station X has returned results of, say, 3,000 votes, in favour of a particular candidate. Protesting voices to this kind of results were usually stilled and sternly told to challenge the results in the law court if they so wished.

A variant of this method exists: a favoured candidate who scored only 100 votes could have a zero added to the end of his results thus giving him 1,000. The reverse situation has also been known to happen. The tedium of counting thousands of ballot papers and the sheer human pressure at collating centres have been known to cause genuine counting errors [15].

Bandwagon Effect

General elections are held with one, two, or three elections every weekend usually starting with the highest offices, i.e. presidency and governorship. The party that emerges the winner makes it clear in subsequent campaigns that it is in charge and any one that does not vote its way in subsequent elections risks being in the opposition. And, of course, being in the opposition means that one's community might not benefit from the juicy government patronage. Thus one is forced to join the bandwagon of the winning party.

Table 1: Methods Used to Rig Elections in Developing Countries.

Rigging method	Perpetrators	How it is done	Effect on Election
Violence	<ul style="list-style-type: none"> • Politicians • Political Thugs 	<ul style="list-style-type: none"> • Harass and intimidate voters • Kill opponents • Burn properties • Pour indelible ink into ballot box • Hijack ballot box from polling station 	<ul style="list-style-type: none"> • Low voter turnout • Distorted results
Under-age voting	<ul style="list-style-type: none"> • Children below voting age 	<ul style="list-style-type: none"> • Register children below voting age • Under-age children vote 	<ul style="list-style-type: none"> • Inflation of voting population • Incorrect election results
Multiple Registration of voters	<ul style="list-style-type: none"> • Politicians • Political thugs • Poll workers 	<ul style="list-style-type: none"> • One voter registers in many localities • One voter acquires multiple voter's cards 	<ul style="list-style-type: none"> • Inflation of voting population • Denial of access to opponents • Registered voters population inconsistent with demographic data
Stuffing of Ballot boxes/Multiple voting	<ul style="list-style-type: none"> • Politicians • Political thugs • Poll workers • Law enforcement agents 	<ul style="list-style-type: none"> • Politicians acquire multiple ballot papers illegally • One voter casts multiple votes in one polling station or in many polling stations on Election Day • Thugs stuff multiple ballot papers in ballot box • Ballot boxes detoured into private homes and stuffed with ballot papers 	<ul style="list-style-type: none"> • Poor results • Premature end of election • Disenfranchisement of voters • violence
Inflation of votes cast	<ul style="list-style-type: none"> • Politicians • Political thugs • Poll workers • Law enforcement agents 	<ul style="list-style-type: none"> • Vote totals submitted for tabulation higher than legal maximum value for polling unit • Arbitrary vote assignment to favour or disfavour candidates • Genuine counting errors due to tedium of tabulation process 	<ul style="list-style-type: none"> • Poor results • Loss of transparency • Violence • Too many electoral litigations • Loss of confidence in election
Bandwagon effect	<ul style="list-style-type: none"> • Electoral Commission 	<ul style="list-style-type: none"> • Hold one election (out of many) at a time • Declare results of one election (out of many) at a time 	<ul style="list-style-type: none"> • Voter's mind biased in favour of a particular party in subsequent elections • Low voter turn-out in subsequent elections • Subsequent elections not free and fair

The bandwagon effect impacts negatively on elections in two important respects: a voter whose party lost in the first election begins to believe that it would be useless to participate in further elections since this might not make any difference. This *déjà vu* attitude reduces voter turn-out in subsequent elections with the resultant

domino effect that more rigging could be perpetrated because if you do not come out to vote, someone else might vote in your place and against your party. The second negative aspect of the bandwagon effect is that subsequent elections are neither free nor fair since the voter's

mind has already been biased in favour of a particular winning party.

FURTHER FEATURES OF THE ELECTRONIC VOTING MACHINE

The electronic voting system to be used should be able to address the problems enumerated above fully. Other variables of the election environment necessitate the system to be deployed to have the features given in Table 2.

Convenience of Use

A great proportion of the voters is either completely illiterate or have barely passable level of literacy. A machine that will be successful in developing countries must have a simple user interface so that it can easily be used by both literate and illiterate voters [9], [18]. The operation of the machine must not be too complex for the poll workers.

Independence of Public Power Supply

In most rural areas of developing countries the public power supply is completely unavailable and even in the urban areas where they exist, their existence is mostly symbolic because of the

unstable nature of the electricity supply. The electronic voting machine must, therefore, rely on some form of battery for its power supply.

Rapid Declaration of Results

The traditional ballot box method of conducting elections takes three to four days or more to have the results of an election declared. The electronic method on the other hand takes only three to four hours. This faster declaration of results removes the perception of the behind-the-scene manipulations from the minds of the voters thus enhancing more confidence in the electoral process.

Permanent Results Storage

In developing countries most of the elections are decided at the tribunals. At this stage legal finesse rather than the transparency and accuracy of elections wins the day. The ballot papers are not easily re-countable. When this process becomes a necessity the tedium and pressure of the election environment add to further errors. This form of error can be prevented if an accurately reproducible count of the result is stored permanently in memory. This result should be tamper proof.

Table 2: Additional Desirable Features of EVM in Developing Countries.

Feature	Why it is desired
Simple Interface	<ul style="list-style-type: none"> • Majority of voters have reading disability • All poll workers must not be computer literate
Battery Powered	<ul style="list-style-type: none"> • Electricity supply unreliable • Electricity supply unavailable in most rural areas
Rapid Declaration of Results	<ul style="list-style-type: none"> • Enhances confidence in electoral process • Removes the perception of behind-the-scene manipulations from the minds of voters
Permanent Results storage	<ul style="list-style-type: none"> • To be tendered in court in case of dispute
Accuracy of Results	<ul style="list-style-type: none"> • Voters preferences should be correctly reflected • Elimination of spoilt ballots cases
No more paper ballots and other stationeries	<ul style="list-style-type: none"> • Long term reduction of cost of election • Paper ballots in any form can be manipulated

Accuracy of Results

The firmware for the machine should be accurate and consistent. It should accurately register the voter's preferences. There should be no spoiled ballot as can happen with the ballot papers when a voter does not register his thumb print correctly. The issue of tender ballot will no longer be necessary.

No More Paper Ballots

The politician has learnt to thoroughly manipulate the paper ballots. In a completely electronic system no form of paper should be used for the casting of votes. The electronic system is initially capital intensive but the complete elimination of paper ballots and other stationery items such as stamp, ink and stamp pads, ballot envelopes ball point pens and pencils, which are very expensive, will make the system cheaper ultimately.

CONFIGURATION OF THE ELECTRONIC SYSTEM

The features that have been enumerated earlier should be built into a machine to be deployed in developing countries. Our task is to realize a machine that has the given features and which also solves the problems of our elections.

The problems of violence and under age voting are mostly attitudinal and are not easily amenable to machine solutions.

The system that we have conceived to solve the rest of the problems is depicted in Figure 1. The interaction with the system starts during the registration of voters. In addition to other data, the voter's biometric data (namely the fingerprint) is captured during registration. The fingerprints are stored in a database of fingerprints only in such a way that the identity of the individual will not be easily traced to the fingerprints. After the registration exercise voters' fingerprints from various localities are compared and analyzed to prevent multiple registrations.

An individual who is found to have engaged in multiple registrations is penalized either by removing extra registrations or by having him completely de-registered. In practice complete de-registration is preferable in order to discourage this kind of fraudulent behaviour. This also simplifies the management of Election Day procedures as the voters do not have to roam about in order to find where they should cast their votes. The remaining fingerprints are transferred from the database containing the fingerprints to the memory of the individual machines designated for particular polling stations. In the system being described the voter can only cast his vote where he registered. The system is not based on any network since facilities for such networks are not easy to come by in developing countries. Moreover security problems with network based voting systems could be overwhelming [9], [10], and [14].

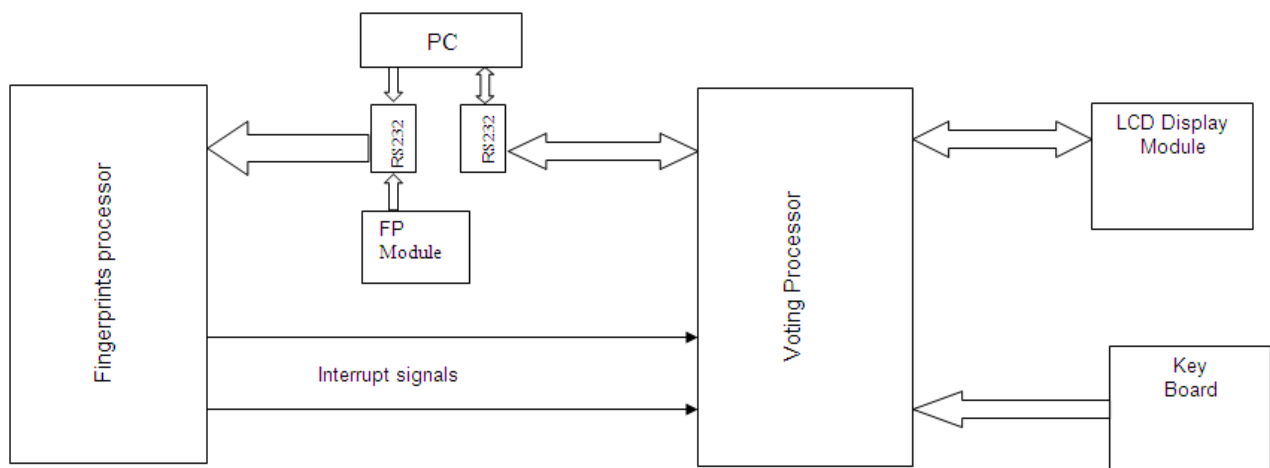


Figure 1: Configuration of Electronic Voting Machine (Note: FP is Fingerprint Module).

On Election Day a poll worker takes the machine to the polling station. The poll worker (presiding officer) does not need to have any knowledge of computer. Once he gets to the polling station he simply turns on the machine by pressing a power switch; he then waits for voters to show up. When the voter shows up at the designated polling station to cast a vote, he performs a self accreditation by simply placing his finger on the fingerprint scanner. The voter's fingerprint is captured and compared with those in the memory of the machine for identification. The machine permits the voter to cast a vote for the candidate of his choice if he is registered and has not already cast a vote.

A similar automated fingerprint identification system has been used in the Venezuelan presidential election in June 2006 [20]. In addition to the voter's fingerprints other data about the election such as the date of the election, the state, the local government, and the polling station where the machine will be deployed are all transferred to the memory of the machine. Since the machine can be used for up to seven simultaneous elections, the types of elections are also stored in the memory of the machine. This initialization process should be done in the office of the Electoral Commission immediately after the voter's registrations have been concluded. The machine is ready to be used in elections after this process.

By this process the problems associated with the stuffing of ballot boxes/multiple voting are completely eliminated. Having been identified the voter casts his vote on the machine by the use of push buttons. The interface of the machine is shown in figure 4. Each button bears the logo of a political party involved in the election as well as the party's acronym. In order to solve the problem of the bandwagon effect, the machine has been designed so that all elections to all offices can be held simultaneously.

For the Nigerian election environment the machine has been designed so that all seven elections (Presidency, Governorship, Chairmanship, Senate, House of Representatives, House of Assembly, and Councillorship) or any combinations of the seven elections can be held in one day. This will, as well, save cost not only for the stationery requirements but also for the remunerations payable to poll workers. The elections are arranged in a hierarchical order beginning with

the Presidency and ending with the Councillorship. The voter identifies the party he wishes to vote for and then presses the button for that party. This vote is recorded in the non-volatile memory of the machine. The voter can cast as many votes as the number of simultaneous elections being held after which the machine disallows him from casting any further votes. Once he completes his votes the voter's fingerprint is stored in another section of the fingerprint processor's memory so that the same voter cannot vote a second time on the same machine nor can he vote on another machine since he is not registered there.

At the end of the election the results can immediately be made known to the voters or the polling agents at the particular polling station by displaying them on the LCD screens which are integral to the machine. The collation (or tabulation) of results is done by taking the machine to a central collation point where the machine is connected to a computer. A copy of the results in the memory of the machine is transferred to this computer. When results from the various machines used in a locality have been transferred, the software in the computer automatically tabulates and declares the results of the elections.

RESULTS

A prototype of a Direct Recording Electronic (DRE) voting machine that solves the problems enumerated and that possesses the desired features has been built. Figures 2, 3, and 4 show various views of the machine including the simple interface. The machine can accommodate 64 political parties or candidates and can be used for seven simultaneous elections. These numbers can easily be varied using the machine firmware.

The machine was realized using two PIC18F2685 microcontrollers. The code for the PIC18F2685 microcontroller which constitutes the firmware for the machine was written in assembly language. Various code protection schemes were employed to make the code virtually impossible to hack. The tabulation software that was developed digitally signs every file created when the results from a machine are transferred to the computer. This protects the data generated by the machines. It is also a means of scrutinizing data at various stages of results tabulation so that the possibility of tampering with results by anyone is removed.



Figure 2: Testing the EVM Circuits.

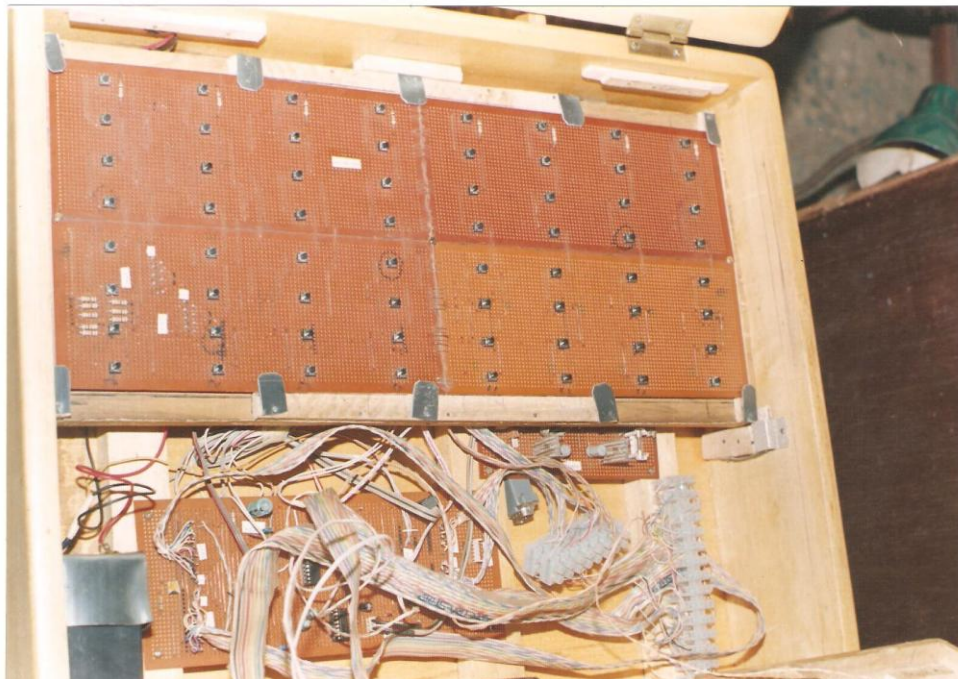


Figure 3: Inside View of the EVM Showing Circuit Boards.

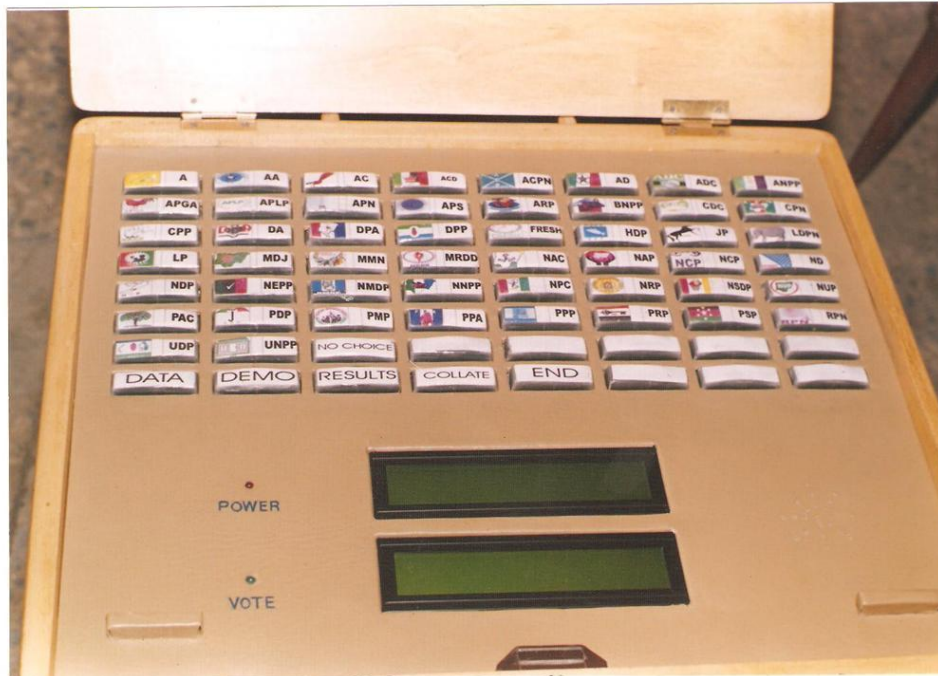


Figure 4: View of EVM Showing the Simple Interface.

The machine has undergone extensive testing for more than 18 months in various locations in Nigeria. The machine was exhibited at the third Nigerian Universities Research Fair (NURESDEF) held in Lagos in March, 2008. It has also been presented in Abuja to the Electoral Reform Committee (ERC) set up by the President of the Federal Republic of Nigeria and it has been observed to be excellent in performance.

CONCLUSIONS

The use of election systems that depend on the ballot box and paper ballot will always result in elections whose results will be unsatisfactory. This is because politicians, especially in the developing countries, have devised many ways of defeating such systems. The only means of conducting free and fair elections that will give transparent results is, perhaps, by the use of electronic voting systems. Such systems must be crafted to correctly solve the problems of the particular locality where they will be deployed. An example of a system that solves the problems of the Nigerian election environment and, indeed, those of other developing countries has been designed and built.

In Nigeria section 53(2) of the Electoral Act 2006 [7] states: "The use of electronic voting machine for the time being is prohibited". Such laws must be repealed in countries where they exist to pave way for the deployment of electronic voting systems and hence for better and more acceptable elections that will guarantee stable and prosperous democracies.

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ABOUT THE AUTHORS

Engr. Dr. Jonathan A. Enokela is a lecturer in the Department of Electrical/Electronic Engineering at the Federal University of Agriculture, Makurdi, Nigeria. He has taught various aspects of analog and digital systems design to both the undergraduate and postgraduate students. He is a registered engineer with the Council for Regulation of Engineering in Nigeria (COREN) and has a wide range of practical experiences. His research interests include embedded systems design and applications.

Engr. Prof. Charles C. Osuagwu is a professor in the Department of Electronic Engineering at the University of Nigeria, Nsukka where he is also the director of the Computer Communications Centre. His areas of interest include digital signal processing and software engineering.

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