A PC-Based Open-Source Voting Machine with an Accessible Voter-Verifiable Paper Ballot

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ABSTRACT

Voting is the foundation of a democratic system of government, whether the system uses direct or representative governance. The heart of voting is trust that each vote is recorded and tallied with accuracy and impartiality. There is no shortage of historical examples of attempts to undermine the integrity of electoral systems. The paper and mechanical systems we use today, although far from perfect, are built upon literally hundreds of years of actual experience.

1. Introduction

Voting is the foundation of a democratic system of government, whether the system uses direct or representative governance. The heart of voting is trust that each vote is recorded and tallied with accuracy and impartiality. There is no shortage of historical examples of attempts to undermine the integrity of electoral systems. The paper and mechanical systems we use today, although far from perfect, are built upon literally hundreds of years of actual experience.

The Open Voting Consortium (OVC) is creating an open source, trustworthy, cost effective, voter verifiable voting system using open source software components on industry standard computers. A primary element of this Open Voting system is the use of software through which the voter creates a *printed paper ballot* containing his or her choices. Before casting his or her ballot the voter may use other, independently programmed, computers to verify that the ballot properly reflects the voter's choices. The voter may also visually inspect the text printed on the paper ballot. The paper ballot is cast by placing it into a ballot box. Once cast, that paper ballot is the authoritative record of the voter's choices for the election and for any recount of that election. Open Voting ballots are machine-readable and may be tabulated (and re-tabulated in the case of a recount) either by computer or by hand.

Open Voting systems can be engineered to accommodate the special needs of those who have physical impairments, or limited reading ability.

voting machines carry a more precious burden — there is no way to buy insurance or to set aside a contingency fund to replace a broken or tampered election.

There are several areas of concern regarding the new generation of computerized voting machines:

- No means for the voter to verify that his or her votes have been tallied properly.

- No means outside of the memories of the voting machines themselves to audit or recount the votes.

- Lack of ability to audit the quality of the software. Fortunately the widespread belief that "computers are always right" is fading. Our individual experiences with error-ridden software on personal computers and consumer products (e.g., the BMW 745i), software errors by even the best-of-the-best (e.g., NASA and the loss of the Mars Climate Orbiter), and the possibility that intentional software bugs can be hidden so deeply as to be virtually invisible (Ken Thompson's famous 1984 paper — Reflections on Trusting Trust) have all combined to teach us that we should not trust software until that trust has been well earned. And even then, we ought not to be surprised if unsuspected flaws arise.

- Vulnerability of the machines or of their supporting infrastructures to intentional

2. OVC System Description

The OVC system will be very much like a traditional system in which the voter enters the polling place, marks his or her choices onto a paper ballot, and inserts the ballot into a ballot box. Our design applies computer technology to that traditional system. However, unlike some of the other computerized voting systems that change the basic nature of the traditional system, our design applies computer technology only in a limited and conservative way.

3.1 Diebold AccuVote TS and TS-X

A group led by Avi Rubin and Dan Wallach analyzed the Diebold AccuVote TS DRE voting machine and found numerous flaws. SAIC was commissioned by the state of Maryland to analyze the Diebold voting system and found “[t]he system, as implemented in policy, procedure, and technology, is at high risk of compromise.” Based on these reports, the California Secretary of State’s office established security procedures for DRE voting machines. Diebold was then found to have used uncertified software in 17 counties in California. The California Secretary of State then decertified the Diebold and all other DREs on April 30, 2004.

3.2 Electronic Systems and Software iVotronic

ES&S iVotronic is a poll-worker-activated, multilingual touch screen system that records votes on internal flash memory. A poll worker uses a cartridge-like device called a Personal Electronic Ballot (PEB) to turn the machine on and enable voting. Voters first choose their ballot language and then make their selections via a touch screen. When the polls close, poll workers read summary data from each machine onto the PEB via infrared. The PEBs are then transported to election headquarters or their contents transmitted via a computer network.

3.3 Hart InterCivic eSlate

Hart's eSlate is a voter-activated multilingual voting system where the voter turns a selector wheel and set of buttons to indicate their votes. The eSlate terminals are connected via daisy-chained serial cable to a central controller, the Judges' Booth Controller (JBC), which provides power, vote activation, and vote storage for up to twelve eSlate terminals. A poll worker issues a 4-digit PIN to the voter using the JBC. The voter enters this PIN on an eSlate and votes using its selector wheel and buttons. Once the vote is cast, the vote is transmitted via a cable to the JBC and stored in flash memory on the JBC's Mobile Ballot Box (MBB). The MBB is then either physically transported to election headquarters or its contents transmitted via computer network.

3.4 Paper Ballots with Optical Scan Machines

There are several problems with the use of paper ballots that are optically scanned with mark/sense-type tabulation systems. The paper ballot is not accessible to the visually impaired or reading impaired. And the paper ballot must be available in multiple languages as required by the jurisdiction. The use of paper does enable recounts, but potentially suffers from the problems of overvotes, undervotes, and improper changes to ballots (including extraneous marks, which would void the ballot).

AutoMark

The AutoMark system is an Electronic Ballot Marker (EBM) that addresses accessibility problems by using an interface comparable to a Direct Recording Electronic voting machine. Similarly, it can provide support for multiple languages and limit overvotes and undervotes through its user interface. AutoMark uses ballots identical to those also used for manually-marked optical-scan systems. AutoMark effectively replaces the pen in such systems with a marking device that supports multiple languages and detects overvotes and undervotes. So there is the question of whether the printed ballots are in each required language, so that a non-English-speaking voter can still verify his or her ballot. It is possible to have a device with accessible output modes that reads the voter's marked choices (like that of OVC system described in Section 5.1.7), so that the voter may verify that the ballot is marked correctly, but that is not currently part of the AutoMark system. A key benefit of the AutoMark system is that the same optical scan tabulation system can be used for ballots cast in polling places, absentee ballots, and provisional ballots. But they neither maintain an electronic audit trail nor use digital signatures to detect ballot stuffing.

4. Why an Accessible Voter-Verifiable Paper Ballot

Many computer and other experts have joined VerifiedVoting.org's call for "the use of voter-verified paper ballots (VVPBs) for all elections in the United States, so voters can inspect individual permanent records of their ballots before they are cast and so meaningful recounts

may be conducted. We also insist that electronic voting equipment and software be open to public scrutiny and that random, surprise recounts be conducted on a regular basis to audit election equipment."

4.1 Paper Receipts vs. Paper Ballots

We speak of OVC creating a paper *ballot*, not a receipt, nor simply a "paper trail." That is, for OVC machines, the printout from a voting station is the primary and official record of votes cast by a voter. Electronic records may be used for generating preliminary results more rapidly or for auditing purposes, but the paper ballot is the actual official vote document counted.

4.2 Paper Audit Trail Under Glass vs. Paper Ballot

While "paper audit trail under glass" does indeed do a pretty good job of preventing ballot box stuffing with forged physical ballots, this approach is not the only—nor even the best—technique to accomplish this goal. We plan for OVC systems to incorporate cryptographic signatures and precinct-level customization of ballots that can convincingly prove a ballot is produced on authorized machines, at the polling place, rather than forged elsewhere. For example, a simple customization of ballots is a variation of the page position of our ballot watermarks in a manner that a tamperer cannot produce in advance. Surprisingly much information can be subtly coded by moving two background images a few millimeters in various directions. Another option is to encode a cryptographic signature within the barcode on a ballot—in a manner that can be mathematically proven not to disclose anything about the individual voter who cast that vote, but simultaneously that cannot be forged without knowledge of a secret key, which is known only to that electronic voting machine.

4.3 Accessible Voting

One of the key benefits of electronic voting machines is to allow disabled voters to vote unassisted. However, as the movement for a voter-verifiable paper audit trail grows, there is a need for the paper audit trail to be accessible as well. The Open Voting Consortium's voting system is designed to be accessible for both entering the votes and verifying the paper ballot produced.

5. OVC System Overview

The Open Voting Consortium (OVC) is developing a PC-based open source voting machine with an accessible voter-verified paper ballot. We intend to use an open source operating system for the PC, such as Knoppix, a variant of Linux that boots off of a CD. The polling place system consists of a Voter Sign-in Station, an Electronic Voting Station, an Electronic Voting Station with a Reading-Impaired Interface, a Ballot Verification Station, and a Ballot Reconciliation Station. See Figure 1. In addition, there are components at the county canvassing site that are discussed only briefly in this paper.

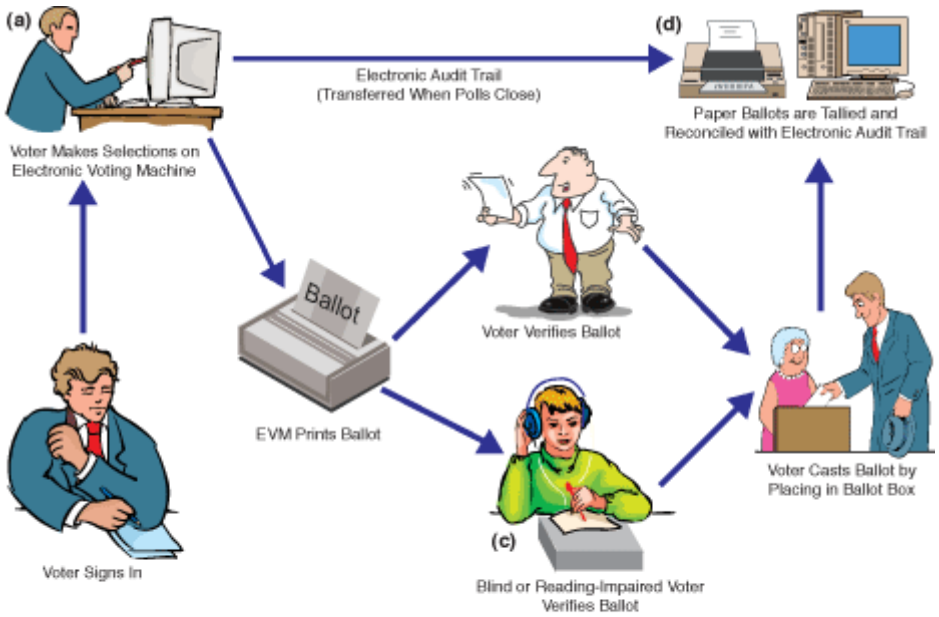

Figure 1. Schematic of Precinct/Polling Place Element.
(a) Electronic Voting Station
(b) Electronic Voting Station with Reading-Impaired Interface (not shown)
(c) Ballot Verification Station
(d) Ballot Reconciliation Station

5.1 Precinct/Polling Place Element

The OVC Precinct/Polling Place Element is intended to provide all of the systems and procedures required for a polling place except for voter rolls, sign-in books and the like. The OVC system will be flexible so that it will be adaptable to applicable laws as well as local preferences.

5.1.1 Voter Sign-in Station

The Voter Sign-In Station is used by the poll worker when the voter signs in and involves giving the voter a "token." It is a requirement that each voter cast only one vote and that the vote cast be of the right precinct and party for the voter. The "token" authorizes the voter to cast a ballot using one of these techniques.

- Pre-printed ballot stock
    - Option for scanning ballot type by EVM

- Poll worker activation
- Per-voter PIN (including party/precinct identifier)
- Per-party/precinct token

5.1.2 Electronic Voting Station

The Voting Station is the voter's primary point of contact with the OVC system. After the voter signs-in, a poll worker will direct the voter to a Voting Station.

The Electronic Voting Station consists of these components:

- A computer, preferably stock commodity hardware, with these features:
  - A monitor, preferably LCD, possibly 15" or 17" touch-screen measured diagonally.
    - One or more input devices, such as:
      - Touch-screen interface on LCD screen
      - Mouse
      - Keyboard
      - Buttons surrounding the screen, like on an ATM
      - Numeric keypad
      - Symbolic keypad
  - Possibly a smart card reader/writer
- A CD-R drive. The CD-R will contain:

5.1.3 Electronic Voting Station with Reading Impaired Interface

The Electronic Voting Station with Reading Impaired Interface is a computer similar to the Electronic Voting Station described above that includes auditory output of the ballot choices and selections made and also includes additional modes of making selections suitable for the blind or reading impaired. Whether these features are integrated to a common voting machine with all functionality, or whether there is a separate configuration for the disabled, is an open question. For example, additional modes of input may be useful for those who can read printed materials, but have physical limitations. The ideal is a universal design that accommodates all voters.

5.1.4 Paper Ballot

The paper ballot is generated by the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface. It is the paper on which the voter's choices are recorded. It must be "cast" in order to be tallied during canvassing, testing, or a manual recount.

5.1.5 Privacy Folder

The paper ballot contains the voter's choices in two forms: a form that can be read by people and a barcode that expresses those choices in a machine-readable form.

5.1.6 Ballot Box

This is a physically secure container, into which voters have their paper ballots placed, in order to "cast" their votes. The mechanical aspects of the voting box will vary from jurisdiction to jurisdiction, depending on local laws and customs.

5.1.7 Ballot Verification Station

The Ballot Verification Station reads the ballot produced by the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface and speaks (auditorily) the selections on the voter's ballot. A count is kept of usage, including counts of consecutive usage for the same ballot, but no permanent record is kept of which ballots are verified.

The Ballot Verification Station reads the same portion of the paper ballot read by the Ballot Reconciliation Station, including the barcode and, ideally, the text via OCR.

5.1.8 Ballot Reconciliation Station

The Ballot Reconciliation Station reads the paper ballots and reconciles them against the Electronic Ballot Images (EBIs) on the CD-Rs from the Electronic Voting Station or the Electronic Voting Station with Reading Impaired Interface. The purpose of reconciling the paper ballots with the electronic ballot images is to prevent ballot stuffing.

5.1.9 Box for Spoiled Ballots

When a voter spoils a ballot, perhaps because the ballot does not accurately reflect her preferences, the ballot is marked spoiled and placed in a box for spoiled ballots for later reconciliation.

5.1.10 Box for Provisional Ballots

When a voter shows up at a polling place and does not appear on the voting roll or the voting roll shows that the voter was sent an absentee ballot, then the voter is allowed to vote by being given a "token" for a provisional ballot. A distinctive smart card or a provisional "blank" ballot or even

a distinctive privacy folder is given to the voter. When the voter has printed the provisional ballot and hands it to the poll worker, the poll worker seals the provisional ballot in an envelope along with the details necessary to determine whether the ballot should be counted and places the provisional ballot in a box for provisional ballots for later reconciliation.

5.2 Absentee Ballots and Manual Polling-Place Ballots

Paper optical-scan ballots will be used for absentee ballots and also for the manually cast polling-place ballots.

5.2.1 Format and Marking

The format and marking of the absentee ballots will be similar to those of existing optical scan ballot systems.

5.2.2 Acceptance at Polling Place

When an absentee ballot is received at a polling place, a poll worker checks the identification of the person delivering it, places on the envelope a sticker from the absentee ballot audit sheet, and places it in the absentee ballot box.

Manual polling-place ballots are placed in the manual ballot box.

5.2.3 Acceptance by Mail or In-Person at County

When an absentee ballot is received by mail, a county poll worker places on the envelope a sticker from the absentee ballot audit sheet, and places it in the absentee ballot box. When an absentee ballot is hand delivered at the county canvassing site, a county poll worker checks the identification of the person delivering it, places on the envelope a sticker from the absentee ballot audit sheet, and places it in the absentee ballot box.

5.2.4 Validation

The process for validating absentee ballots is comparable to the current process, with the notable exception that the sticker must be present on the envelope. The database record for the voter needs to be marked to indicate an absentee ballot was cast. When a voter casts an absentee ballot also casts a provisional ballot, the provisional ballot will not be counted. The ballot is separated from the envelope for canvassing.

5.2.5 Canvassing

A canvassing system for absentee and provisional ballots will be developed that reads in each optically scanned ballot to create an electronic ballot image. These electronic ballot images are aggregated with the scanned or reconciled versions of the electronic voting machine-printed paper ballots.

5.2.6 Reporting

Reports are made available by precinct for the vote totals for the combination of absentee and provisional ballots. The number of absentee and of provisional ballots is also made available by precinct.

6. Conclusion

The Open Voting Consortium has demonstrated a voting system based on a PC-based electronic voting machine with voter-verifiable accessible paper ballot. We have described the design for the production system we propose to build, based on the prototype we have built and the lessons learned in the process. In the development of this system, we expect to enhance the state of the art in building reliable and trustworthy computerized systems. However, it is not merely the software and hardware components that are of concern; the voting processes and procedures are also key to the development of a reliable, secure, trustworthy and accessible system.

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We propose that each polling place include a Ballot Reconciliation System (BRS) (described below) that has a sheet fed scanner for reading the barcode. The BRS has other benefits in support of auditing the system, also described below.

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