An Electronic Secure Voting System Based on Automatic Paper Ballot Reading

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Abstract. A secret and secure ballot is the core of every democracy. We all feel proud of being able to decide the future of our countries by making appropriate use of our right to vote in an election. However, how can we improve the efficiency of the voting process? Democratic governments should have mechanisms which ensure the integrity, security and privacy of its citizens at the polls during an election process. This paper describes a new electronic secure voting system, based on automatic paper ballot reading, which can be utilized to offer efficient help to officials and party representatives during elections. It presents how the system is organized, it also describes our OCR system and how it is implemented to read paper ballots, and it ends showing some experimental results.

1 Introduction

Due to the rapid growth of computer networks and advances in cryptographic techniques, electronic polling over the Internet is now becoming a real option for voters who have access to the Net. However, electronic democracy must be based on electronic voting systems that have the following properties as described by Cranor et al [1]: *Accuracy, Invulnerability, Privacy, Verifiability and Convenience*. Internet voting systems are still under development and we think that it will take time before they can become widely available to all citizens [2], [4]. This paper describes a new electronic voting system that is accurate, invulnerable, private, verifiable, convenient and compatible with electoral tradition in our country. It uses OCR techniques to automatically read paper ballots and GSM techniques to transmit electoral results to the central electoral office where results coming from all voting boxes will be counted.

2 A Proposal for an Electronic Voting System Architecture

Any new proposal for a new Voting Systems should take into account all of the characteristics defined in [1] and it should pay special attention to two key points, “No Digital Division” and compatibility with electoral tradition in each country.

The electronic voting system that we present allows to make compatible traditional voting methods with automatic reading of paper ballots, automatic vote counting

system and a way of transmitting election results by using GSM network to the Data Center where final count of all the data coming from all the Electronic Ballot Boxes takes place.

Figure 1 shows the proposed architecture. On the left, Electronic Ballot Boxes (EBB) are shown, i.e. computer systems based on OCR techniques that automatically read the paper ballots, fully compatible with traditional paper ballots, and voters use them to cast their ballots. Once the election is over, each EBB will transmit its results through the GSM network by using Short Message Service (SMS) that allows short messages to be sent in a secure way from the ballot box to the Short Message Service Center (SMS-C). These messages are stored in memory until they are read by the API specific functions of the SMS-C server that are executed under control of the application being executed in the Vote Server.

Fig. 1. Architecture for electronic voting system

3 Automatic Paper Ballot Reading

The ballot box is identical to a traditional one in our country, the only exception being that an electronic lid has been added. This lid has two input slots for ballots; one for validation and one for counting. The ballot adheres to traditional ballot papers with one electoral possibility printed on it and a special strip where a non-visible text is written (Fig. 2). This text is visible using ultraviolet light. After checking the correspondence between the visible and non-visible text, the ballot is folded, occulting only the visible text (Fig. 2). Therefore the proposed system absolutely fulfills the privacy requirement. This ballot is introduced to the first slot and once it has been recognized and validated by the electronic lid, it is introduced to the second slot. The vote is then counted.

3.1 Image Acquisition and Preprocessing System

The main function of the circuit is accomplished when a digital image of what a camera is seeing is saved in a memory. Due to the critical application of the system, the image has to be processed to obtain the required quality so that the optical recognition of characters is fast and accurate.

In order to achieve the objectives stated above the image is treated on two different planes. The first involves the optical part of the image capture. The system uses an

Fig. 2. An example of ballot for the electronic voting system and ballot after being folded ready to be introduced into the ballot box

Fig. 3. Images of the paper ballot grabbed using ultraviolet light

adequate illumination and optical filter to obtain the best possible image. Once the image has been digitalized, it enters the second plane where it is treated to obtain a good monochrome picture which will later be read by OCR software. In this application, the characters are black over white background but the procedure would be similar if the characters were white over black background. Figure 3 shows images of paper ballots grabbed by our system using ultraviolet light and ready to be read by the OCR.

The digital processing of the image is done in four different stages: *Correction of non-uniform illumination, Adaptive image enhancement, Adaptive binarization, and Median filtering.*

3.2 Optical Character Recognition Algorithm

The ballot is automatically read by means of an OCR software specifically designed to accomplish this task. There are several research works that were taken into account to design and implement our OCR system. Some works offer solutions based on the smallest distance [5], other works are related to the use of Bayes statistic classifier or correlation techniques [6]. There has been a great deal of effort in the field

of neuronal nets like it is shown for instance in [7]. Structural methods have been also proposed like in [8] [9]. Finally, several authors proposed methods that combine different techniques [10].

The reading process is based on the fact that each character can be uniquely identified by several features which need to be obtained from the digital image of the ballot. The image of the text to be read is taken by use of ultraviolet light. Aforesaid text is invisible with ordinary light.

The first step of the recognition process consists of extracting from each character the following features: number of groups, number of regions in each group, and position of corners for each region.

A group is composed of a set of horizontal consecutive lines of pixels where all the lines belonging to the same group have the same number of transitions from white to black. The number of regions in a group is equal to the number of transitions from black to white that the group has. Coordinates of corners for all the regions are defined by the position of the first and last pixel of the first line and first and last pixel of the last line. For example, figure 4 shows the character 2 where we have three different groups.

During the following step we try to classify the character by using two kinds of features: simple features and complex features. Using simple features we reduce the number of possible candidates and complex features permitting us to undoubtedly classify the character.

Simple features are extracted processing the character line by line: the number of enclosures and its position in the character; number of concavities, its shape and position in the character; number of groups; number of regions per group. These simple features are used to define a key that allows us to search for the character through the decision tree. If this key only matches one character the identification process finishes indicating that it was possible to identify the character. Should this not be the case, more complex features need to be obtained from the character.

Fig. 4. Groups, regions and floating mask

The process of finding complex features for a character is based on the use of floating masks [3] which are specific for each feature. Therefore, the number of floating masks depends on the number of Complex features to be found, and this depends on the number of characters to be recognised. Depending on the Simple features, the system has to be able to decide which floating masks have to be applied to the character in order to identify it among all the candidates that share the same Simple features. One mask is a group of pixels strategically distributed, in such a way that allows,

comparing with other pixels of the image, an extraction of information about a certain feature of the image.

The mask is a floating mask because it moves over the image. It slides over the character, testing, in adequate points, the presence or not of the feature. There is a movement direction and a floating one. The movement direction is fixed and it is one of the four main directions on the plane. The floating direction will be one of the two perpendicular directions to the movement one, depending on the concrete position of the mask inside the image.

Masks are formed by grid elements, which together define matrixes. Each grid element is equivalent to a pixel and has an associated value: 0 or 1. Testing the feature consists of comparing the value of each grid element with the value of the pixel that is under it at any given time. If values equate then the test is positive, otherwise it will be negative.

Grid elements belong to any of the following three different matrixes:

1. Control matrix: By testing this matrix the floating direction is decided and also, the decision to carry out additional tests by using other matrixes of the mask is taken.
2. Full Coincidence matrix: It searches for a full coincidence of the matrix and image.
3. Partial Coincidence matrix: It searches for a partial coincidence of the matrix and image.

Figure 4 shows an example of a floating mask formed by a Control matrix, and a Full Coincidence matrix, the latter consisting of just one element. This basic mask may be used to detect a horizontal line located at the bottom of the character (for instance in characters 2 or L).

The Mask starts its movement from an initial position inside the image, which is defined during the design process (this will be determined by the desired features that we are looking for). First of all, a control test is performed. If the Control Matrix and the image are coincident the control test is positive. In this case, the Full Coincidence matrix test is carried out. A negative result in this test means that the feature has not been found and the mask should then move one position in the movement direction. If in the new position the control test is negative, the mask advances one position in the floating direction.

These steps are constantly repeated until, either the Full Coincidence matrix test is positive, the mask reaches a final position fixed in the design process, or the Control matrix leaves the character window. This last possibility always happens when the feature cannot be found in the image.

There are several characters where the use of floating masks is absolutely necessary to solve ambiguities among them. Let's consider the following example where we show how to distinguish between the number 8 and the character B (see figure 5). First step consists of designing the appropriate mask to use in this case. It is clear that the main difference between the number 8 and the letter B is the discontinuity that we find in the left side of the number 8 that cannot be found in the letter. This means that the floating masks should be designed to find that characteristic that uniquely identifies number 8. Figure 5 shows one mask that can be used in this case.

Fig. 5. Characters to be identified by using floating mask

The characteristic that we are looking for is located in a well known position of the segmented character. Therefore, we define a control area where the mask is going to be used (see figure 5). The mask starts its movement in this control area from the left bottom corner.

4 Paper Ballot Automatic Reading Experimental Results

Our system has been tested mainly using OCR-B characters font size 18 because paper ballots are written using that font. Floating masks were designed for this font type and size but, as we can see, our system is very robust to variable font sizes. Table 1 shows testing results of our system applied to automatic paper ballot reading. It is important to notice that there are only 8 characters that generate wrong readings, /, \ 0, 2, (,), S and O. If we analyze the path followed by the floating mask during its movement, right reading ratios are dramatically increased (see table 2).

Table 1. Reading results using floating masks designed for OCR-B 18

Character Font size 18	Number of readings	Correct reading rate	Wrong reading rate
0	5000	96,16%	3,84% (identified as O)
2	5000	98,44%	1,56% (identified as Z)
O	5000	97,66%	2,34% (identified as 0)
S	5000	99,42%	0,58% (identified as 5)
(	5000	99,34%	0,66% (identified as I)
)	5000	99,26%	0,74% (identified as I)
/	5000	99,24%	0,76% (identified as I)
\	5000	99,3%	0,7% (identified as I)
All other characters	5000	100%	

Paper ballots are written using OCR-B font size 18 and, as it is shown in table, reading results are very good. Our electronic vote system based on automatic paper ballot reading has been checked in several election processes and results were excellent. Wrong reading ratio is almost zero, because our system is prepared to correct one character bad reading. Don't forget that in several countries electoral options are well known before the electoral day (closed lists), and it is possible to create a Data Base with all these options.

Table 2. Reading results using floating masks designed for OCR-B 18 and analyzing paths followed by floating masks

Character Font size 18	Number of readings	Correct reading rate	Wrong reading rate
0	5000	99,9%	3,84% (identified as O)
2	5000	100%	
O	5000	99,94%	2,34% (identified as 0)
S	5000	100%	
(	5000	100%	
)	5000	100%	
/	5000	100%	
\	5000	100%	
All other characters	5000	100%	

5 Conclusions

Today many researchers are working to develop new voting systems. It is clear that there is a risk. Internet voting systems could be attacked, electronic voting machines could go wrong and the election process could become a total disaster. While it is true that this may happen, it is also true that we need to continue working in this field and should not be deterred by these risks.

The new voting system that we present here has already been checked in limited election processes. It represents a step forward in the development of new electronic voting systems. So far the results have proved to be very good. We have developed a new framework for voting based on an electronic voting system that is able to automatically read ballots. This electronic voting system can be described as an evolution of traditional voting systems where no human is needed to count votes.

Our proposal is based on a new implementation of an OCR system that uses the floating mask concept to read paper ballots. Our experimental tests prove that our system reads with 100 % of good readings.

We believe that this new framework fulfills all of the properties required by electronic voting systems that have been stated in this paper. Research in the field should continue because digitally literate people should use digital equipment to cast their votes.

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