DUAL VOTE: A NOVEL USER INTERFACE FOR E-VOTING SYSTEMS

Damien MacNamara, Francis Carmody, Ted Scully, Ken Oakley and Elizabeth Quane
Department of Information Technology,
Limerick Institute of Technology, Moylish Park, Limerick, Ireland

J. Paul Gibson
Le département Logiciels-Réseaux (LOR)
Telecom & Management SudParis, 9 rue Charles Fourier, 91011 Évry cedex, France

ABSTRACT

The authors present a novel e-Voting system called "Dual Vote", which couples the strength of electronic voting with the traditional pen and paper user interface (UI). Through the use of pen and paper as a voting medium the system addresses usability problems and provides a verifiable audit trail; two issues which have afflicted modern e-voting solutions. The paper presents the implementation details of the Dual Vote system, which is mainly comprised of an inductive sensor array and a capacitive-based electronic pen. An evaluation is also conducted which demonstrates the high level of usability as well as assessing the technical competency of the Dual Vote system.

KEYWORDS

e-Voting, Usability, Audit Trail, User Interface, Verifiability

1. INTRODUCTION

This paper presents a novel e-voting system called Dual Vote. In the Dual Vote system a voter's preference is simultaneously recorded on both electronic and paper media. The Dual Vote system allows a user to enter a vote using the traditional pen and paper interface. The system simultaneously records the vote electronically using an inductive sensor array and a capacitive-based electronic pen. This novel UI addresses the crucial issues of usability and verifiability, which are now widely recognised as being deficiencies in many modern e-voting systems

Usability is a commonly used metric for electronic-voting systems. The issue of providing an effective and intuitive UI has proved a significant challenge for modern e-voting solutions. A recent study Conrad et al, compared the usability of six prominent e-Voting machine interfaces and identified a number of weaknesses [7]. The problems ranged from at best, increasing the effort required to vote to at worst; interfering with the voter's ability to vote as intended. The study showed that voters preferred a short and quick voting experience with a clear negative relationship between effort and satisfaction. The study also found that paper ballot interfaces required the least amount of actions to vote when compared with other types of voting system. In addition, Byrne et al found the overall error rate for paper ballots to be 1.5% which was significantly less than electronic voting [4]. This clearly highlights the ongoing need for improved e-voting interfaces.

Increasing emphasis is also placed on the ability to formally verify the results of an electronic voting system For example, it is now a requirement in twenty-seven states in the US that e-voting systems contain some form of paper audit trail. As another example a group called the Irish Citizens for Trustworthy e-Voting was formed because Ireland's Power Vote system lacked any means of verifiability. The Power Vote system was officially removed from use in 2009 [14].

The Dual Vote interface incorporates an Inductive Sensor Array Reader (ISAR) and a capacitive-based electronic pen. The ISAR is a novel use of inductor technology that allows the system to determine the paper form location and orientation. The pen relays positional data as the user writes on the ballot paper. The software layer couples the location and orientation of the ballot paper with the pen's positional data to elicit the voter's preference.

Section 2 describes the current state-of-the-art in electronic voting systems. Section 3 provides an introduction to the concept of Dual Vote and describes the implementation details of the system. Section 4 presents a detailed evaluation of the usability and technical competency of the Dual Vote system. Finally Section 5 concludes and outlines future directions of research.

2. RELATED WORK

Direct Recording Electronic (DRE) is a classification used to describe an e-Voting machine which stores votes electronically using various user interfaces. Typically touch-screen, push-button and optical interfaces are most commonly used. The electronic interface presented on touch-screen and push button systems is not instantly familiar to the voter and this can lead to usability issues. In optical scan systems where pen and paper may be used to vote, there are two general tasks that need to be carried out in order to vote. Firstly, the voter must vote by usually punching a hole or shading in an area on the paper ballot. Secondly the ballot paper has to be fed into a scanning apparatus.

Recent studies have tested the user interfaces of various models of e-Voting machine. [2, 4, 7, 8]. Conrad et al compared the usability of a DRE machine to traditional methods of voting [8]. The metrics used in this study were time to complete the ballot, number of errors observed and objective satisfaction using questionnaires. The comparative study showed that the DRE performed similarly but not better than the traditional methods. In [4] a study of paper, mechanical and DRE machines (that used an optical scanner to count the votes) revealed that traditional paper based voting was significantly less prone to errors than the e-Voting machines.

As mentioned in section 1.1, verifiability is an important requirement for e-voting with many researchers proposing a paper audit trail for use with existing systems [5, 9, 1, 6]. The best known method for paper audit trail provision was that developed by Rebecca Mercuri termed "Voter Verifiable Paper Audit Trail" (VVPAT) [12]. A VVPAT receipt, while protected behind a transparent window, was printed by the e-Voting machine. Where e-Voting systems use an attached printer to generate a paper trail, the printer is controlled by the software and hence vulnerable to exploitation. A study which examined the practicalities of using a VVPAT system attached to a voting machine revealed significant delays in processing the paper receipts as each receipt had to be separated from a spool of paper before counting [10].

In usability studies involving e-Voting interfaces, subjective usability has often been measured using the System Usability Scale (SUS) [3]. The SUS in usage for many years for global assessment of systems usability is not unique to e-Voting. SUS uses ten 5-point Likert scales to produce an overall mean usability score. A higher score denotes higher perceived usability. The reason for research into usability has been demonstrated in several studies [8, 11, 15, 16] which have shown that poor usability can lead to a complete misinterpretation of the voters intentions leading to a vote for the wrong candidate. Voter perception that their vote was cast successfully leads to higher confidence in the e-Voting system. Finally Everett et al suggest that that usability issues can affect voter turnout if the process takes an excessive amount of time (efficiency).

The authors in proposing the 'Dual Vote' system and implementation have retained the traditional pen and paper system of e-Voting as a means of recording a traditional and electronic vote without performing any additional tasks. From previous studies it has been demonstrated that paper has high usability and low error rates [4]. Our system provides for a highly useable interface and paper audit trail which is generated by the voter.

3. DUAL VOTE CONCEPT

In a Dual Vote system, the UI must be simultaneously capable of creating an electronic and paper vote. Recently moves toward introducing paper audit trails to e-Voting systems have focused on the integration of a printer with the e-voting system. As outlined in Section 2, the interfaces of these systems (touch-screen, push button etc) is not instantly familiar to the voter. The Dual Vote system presented in this paper addresses this issue by allowing a voter to cast his vote using the traditional pen and paper method of voting. The majority of persons should already be familiar with casting a vote in this way. For this reason, the proposed Dual Vote system and UI address both issues of usability and transparency. The primary usability requirement therefore in a Dual Vote system is:

R1: The voter votes by pen and paper.

The terms "pen and paper" are defined as abstract and may themselves contain electronic components. It is the perception of both of these objects from a voter's viewpoint which is important to the authors. The second requirement deals with how the electronic vote is generated from the paper vote. Section 2 has outlined the mechanical and/or usability issues with existing e-voting systems that attempt to provide an audit trail. The Dual Vote system presented in this paper address these issues. This leads to the second and third design requirement:

R2: The transformation of votes between physical and electronic media should minimize the dependency on mechanical components.

The final requirement is concerned with the process/protocol that a voter must follow in order to record their vote. A major criticism of many e-voting systems is that they complicate the voting process [15, 16]. The authors require that the new voting process must be as close as possible to the traditional (non electronic) approach, which will result in the system being more user friendly.

R3: The voting process will mirror the traditional method of voting.

3.1 A Dual Vote System Using Optical Technologies

The proof of concept phase of the development of the 'Dual Vote' system adopted a simple optical interface using a camera placed underneath a writing surface. The code determined the paper orientation and ink marks made by the voter. To test the concept a standard ink pen and a light grade of paper were used. The camera read a mirror image of the ink marks through the underside of the ballot paper. The proximity of the ink marks to printed markers on the underside of the ballot paper were determined. Through this process the system could identify how the vote was cast.

The proof of concept successfully demonstrated that an electronic vote could be determined from a paper vote without the voter having to perform any additional tasks e.g. manually feeding the ballot paper into an optical scanner. Anonymity is a major requirement for any e-Voting system. The presence of a camera in the e-Voting interface may lead to a conclusion that voter privacy may be compromised during voting even if optical design and software techniques were used to prevent identification of the voter. The effect of such voter perceptions on camera-based e-Voting user interfaces are outside the scope of this paper.

3.2 Inductive Interface

This Dual Vote system contains a novel Inductive Sensor Array Reader (ISAR) whose purpose is to determine paper orientation and preference box coordinates when a ballot paper is placed on the voting surface. The key usability requirements (R1, R2 and R3) are independent of any specific hardware.

The ISAR is a term defined by the authors as an interface consisting of an array of inductors. The implemented ISAR comprises of an array of 42 X 32 inductors and is the size of a typical voter writing surface (378mm X 288mm). The ISAR works on the principle that metallic materials of a certain magnetic property will cause a change in the inductance of an inductor in the array when brought close to that inductor. The ballot paper in the Dual Vote system has metallic marker strips attached. When it is place on the writing surface, these metallic marker strips cause the change in the inductance of certain inductors in the array. This inductance change is captured by a measurement system and passed to the system software effectively as a bitmap image. Standard machine vision algorithms are then used to calculate the ballot paper location in relation to the known position of the metallic strips.

3.3 Main Components of the User Interface

Unlike the optical solution, the ISAR may not be used to record the voter's intentions using a standard ink pen. This led to the separation of the UI design process into distinct divisions: (i) Identification of the orientation of the paper form on the writing surface (Locator) and (ii) Determining the voter's intentions (Interpreter). The key components of the UI are illustrated in Figure 1 and include:

D1 The ISAR which will identify paper form orientation. (Locator)
D2 The Digitizer and a hybrid ink/electronic pen which will interpret the voters intentions. (Interpreter)
D3 The interpreter and locator will communicate via the software layer.
D4 The interpreter and locator (Digitizer) are of equal size.

A key decision was taken at the initial stage of this UI development. The digitizer and hybrid pen development would be outsourced to a third party with experience in digital pen and graphics pad technology. Both the locator and interpreter of the UI component would communicate at the software level allowing for independent hardware development. In order to merge digital ink with actual pen ink, the digital pen would need to be a digital / ink hybrid. A third party developer was given responsibility for delivering this component of the UI.

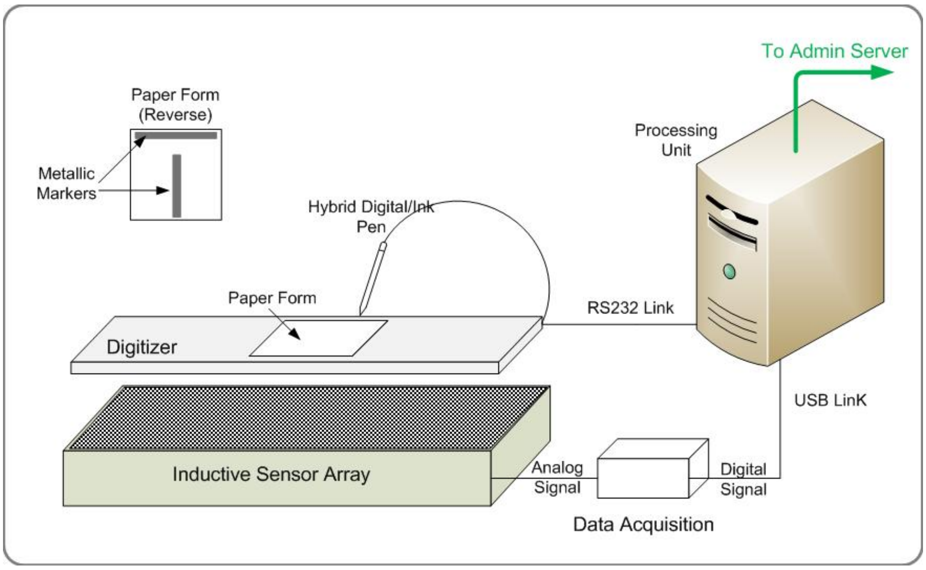

Figure 1. Frequency of Errors Responsible for Misclassification of Votes

3.4 Ballot Paper Design

The design requirements for the ISAR are the same as that of the optical UI. Commonalities were initially identified between the two technologies with regard to ballot paper design in that markers needed to be placed on the back of the ballot paper to identify its orientation and location. The ballot paper design for the ISAR consisted of metallic strips placed on the back of the ballot paper as shown in Figure 2.

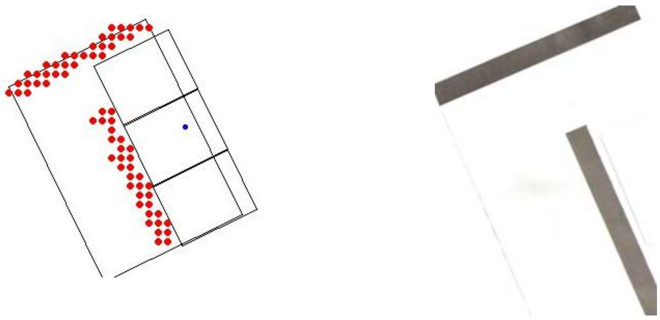

Figure 2. Resulting Image generated by the ISAR versus original image of the underside of the ballot paper. The red dots indicate the metal strips as shown on the right hand side of the image. Note also the blue dot representing a coordinate from the interpreter

Extensive testing was performed on various types of metal to gauge which performed best with ISAR Magnetic shielding foils produced the greatest response from the inductors in the ISAR. The metal chosen was a high permeability, high performance nanocrystalline magnetic shielding alloy sandwiched between layers of clear PET. It is very light weight and flexible. This material was selected based on the responses observed when a strip of the metal was placed within the sensing range of the inductive sensor. Figure 3 shows the output response for any one of the inductors in the ISAR. The graph shows the inductance deviation versus the distance between the metallic strip and the inductor. From this analysis and testing it was possible to determine the deviation threshold level and sensing range of the inductor. The selection criterion was simply based on which metal produced the largest response at the desired distance from an individual sensor in the ISAR.

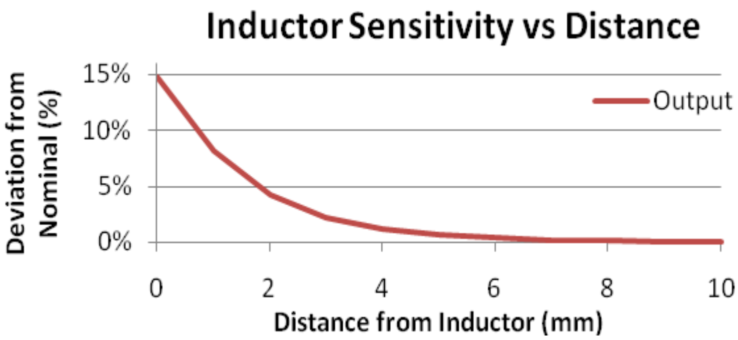

Figure 3. Inductance deviation versus the distance between the metallic strip and the inductor.

Two separate metallic strips were placed on the back of the ballot paper. One was placed horizontally along the top of the ballot paper and the other vertically along the middle side. Based on the sensors that responded when the ballot paper was placed on the surface of the ISAR the software calculated the sensor groups corresponding to each metallic strip. A point of intersection and a slope value was calculated using a least mean squared algorithm. Based on this information the software calculated the orientation and position of the ballot paper on the ISAR surface. Figure 2.0 shows the resulting bitmap produced by the software based on values received from the ISAR.

4. EVALUATION OF THE DUAL VOTE SYSTEM

A field study was setup in the Limerick Institute of Technology in order to evaluate the usability of the ISAR. The purpose of the study was to evaluate the Dual Vote system under two metrics: Subjective Usability and Effectiveness. We also briefly report on Efficiency, giving the mean time taken to vote using the interface.

4.1 Method and Procedure

Participants

The field study consisted of 332 participants who voted using the Dual Vote system. 100 people completed the SUS and demographic survey after they had voted. Regarding gender; 72.2% of respondents were male, 27.8% were female. The age demographic was: 26.8% of respondents were aged 15-24, 50.5% were 25-44, 17.5% were 45-64 and 5.2% were 65+. The education demographic was; 18.6% had completed second level, 56.7% had a degree, 18.6% had a masters degree and 6.2% had a PhD. Additionally the participants were asked to rate their computer experience on a Likert scale of 1 to 10, a higher value reflected more experience. The average self assessed rating was 6.7.

Ballot Design

The ballot paper was a single A5 sheet with two metallic strips affixed to the underside. An RFID tag was also affixed to the underside. The RFID tag contained a code which could be related to the resulting electronic vote during the analysis. The RFID tag contained no information on who the voter had voted for. A choice from three candidates could be selected and the voter was instructed to place an “X” in one of the preference boxes.

Procedure

The voter had to present a student identity card to be issued with a ballot paper. The voter was instructed to place the ballot paper on the writing surface without folding it. (The ISAR could not locate folded ballot papers). The voter then placed the ballot paper into the adjacent ballot box and was asked to complete a survey regarding the usability of the system

Electronic Data Collection

When the voter placed his ballot paper on the writing surface (ISAR), a bitmap of the ballot paper was generated based on the position of the metallic strips. In addition all pen strokes made by the hybrid pen and digitizer (Interpreter) were overlaid on this image. (Pen coordinates are measured in pixels and the ISAR coordinates are measured in mm). A translation from pixel to mm coordinates mapped the coordinates provided by the pen to the ISAR coordinates. Therefore for each voting session, all pen strokes, paper orientation and period for which the ballot paper resided on the writing surface were recorded.

4.2 Evaluation Criteria

4.2.1 Subjective Usability

The SUS survey produced a mean result for the Dual Vote system of 86.1 which indicates that the usability of the system is very high for e- Voting Systems. This result compares favorably with recent studies in [8, 16]. The Dual Vote system achieves the same SUS score as a Direct Record Electronic (DRE) voting machine. The Dual Vote system scored marginally higher than the optical Bubble Ballot but significantly greater than the mechanical lever, punch card and the experimental Pret a Voter ballot interface. This supports the authors assertion that the Dual Vote system achieved the usability requirement.

Table 1. Shows the score of our system compared to other e-Voting machines tested by Everett and Winckler

Method	Average SUS	SD
ISAR	86.1	11.4
DRE	86.1	16.6
Bubble Ballot	81.3	22.2
Lever Machine	71.5	14.8
Punch Card	69.0	22.0
Pret a Voter	68.5	17.8

The SUS questionnaire gave user perspectives on particular aspects of the system: complexity, confidence, ease of use and the willingness of the voter to use the system frequently. Respondents rated their responses on a scale of 1 to 5, where 1 is a strong disagreement and 5 is a strong agreement. Respondents asked about the systems ease of use returned a mean score of 4.61 indicating that respondents strongly agreed that the system was easy to use. Respondents returned an overall confidence mean of 4.31, agreeing that they had confidence using the system. Respondents agreed that they were willing to use the system frequently for e-Voting with a mean score of 4.06. With regards to complexity, the mean score was 1.21 indicating that the respondents strongly disagreed that the system was complex to use.

In addition respondents commented in the SUS questionnaire on voter confirmation and accommodation for left-handed people. The cable coming from the hybrid pen was short and failed to accommodate left handed voters. As no confirmation GUI was included; voters had no way of knowing how the system interpreted their vote. The inclusion of the GUI may alter the SUS score and the authors believe, merits further study.

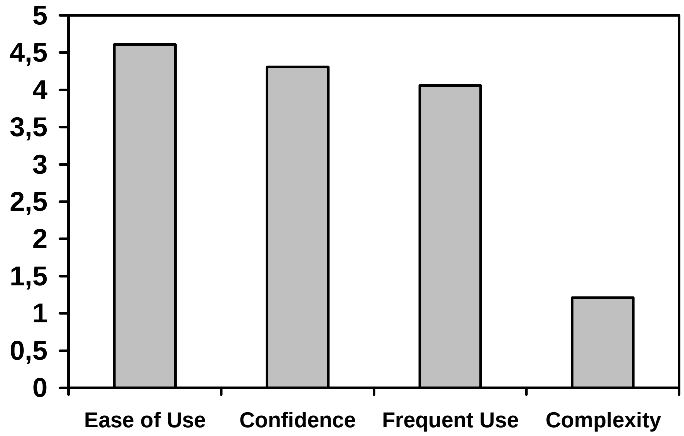

Figure 4. User Perspectives on Dual Vote

4.2.2 Effectiveness

This is expressed as the relationship between the voter's intention and the result produced by the system based on that intention. In some usability studies [7] the voter intentions were made known to the researcher beforehand. In this study, the voter intention was not known to preserve the secrecy of the ballot. However access to the ballot papers was available after the election result was announced. Therefore it was possible to compare the ballot paper to the electronic image by scanning an RFID tag attached to the ballot paper.

A detailed analysis between each physical ballot paper and its corresponding electronic data revealed that out of the 332 votes cast, the Dual Vote system misclassified 38 votes. Therefore, the total error rate of the system for the student election trial was 11.4%. By comparison, a field study by Herrnson and colleagues that tested different types of voting machine, reported error rates of 2-3% where the voter had to select only one candidate [13].

For each vote studied the following four error categories where identified:

- No coordinates collected for the voting session. The pen did not provide any coordinates to the Dual Vote system for the duration of a voter session.
- Unresponsive sensors. The ballot paper positioning algorithm operates based on sensors reacting to the presence of metallic strips on the back of the ballot paper. If sufficient sensors do not react to the metallic strip then the positioning algorithm cannot determine the position of the paper.
- False sensor responses. During testing it was observed that certain sensors may activate and continue to activate without the direct presence of the metallic strips. Depending on the position of such sensors they can interfere with and inhibit the positioning algorithm.
- Lack of rules for spoilt votes. The software maintains a set of rules for identifying spoilt votes. It was observed that the rules did not correctly classify a spoilt vote for one situation.

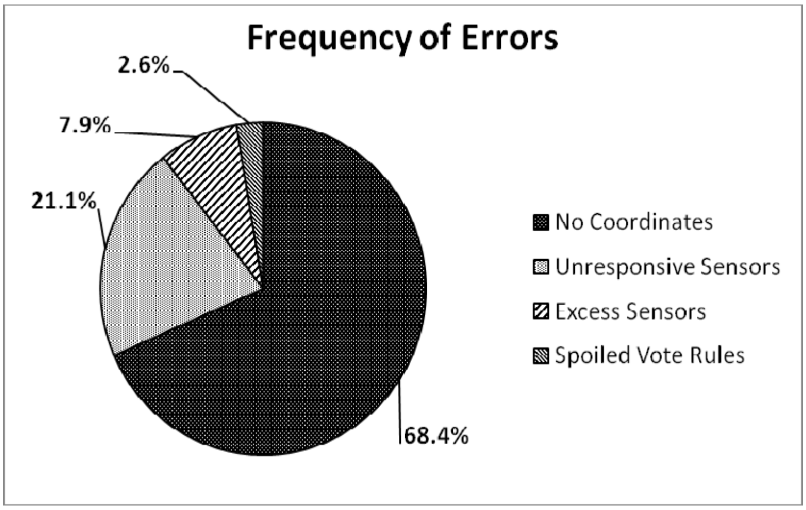

Figure 5. Frequency of Errors Responsible for Misclassification of Votes

The percentage breakdown of the error categories based on frequency is depicted in Figure 5. The majority of errors were due to a lack of coordinates (68.4%). The main cause was found to be a fault with the hybrid electronic pen whose development was ongoing at the time of the trial election. The trial election uncovered an intermittent problem with a component in the pen which meant that while some voters cast their preference as required, the pen did not send the corresponding coordinates to the Dual Vote system, making it impossible to determine the voter's preferences. If the pen component related errors are excluded, the overall error rate of the Dual Vote system drops to 3.9%. It is worthwhile comparing the results of the manual vote with those of the Dual Vote system once the errors caused by the pen component are excluded (see Figure 6). As a result the Dual Vote results are now much more reflective of the actual manual count of the election. The 3.9% figure also compares more favourably with the error rate for single candidate selection in the Herrnson field study of 2006 [13].

Sensor-related issues (unresponsive or false excess sensors) were responsible for a total of 11 misclassifications which will be addressed through a combination of hardware and software refinements. These sensor related errors arose where ballot papers did not lie flat on the writing surface due to folds or creases in the ballot paper. The folds or creases caused portions of the metallic strips to lie outside the range of the ISAR.

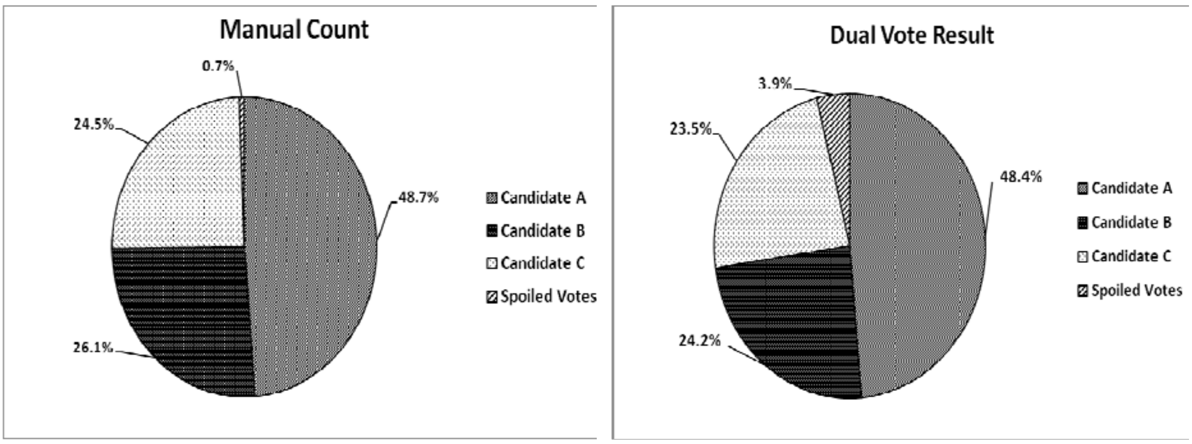

Figure 6. Comparison of error rates between Manual Count and ISAR (excluding pen errors)

A single vote was incorrectly classified for one candidate when it should have been marked as a spoilt vote. The voter marked a single dot within the preference box for this candidate. The Dual Vote system interpreted this as a valid vote as coordinates were received. While the software currently abides by a limited set of rules to identify the spoilt votes, this result highlights the need for a comprehensive set of rules, to deal with spoilt votes. To assist with this task, interviews are currently being arranged with election officials to produce an extensive set of software rules to identify spoilt votes.

Certain aspects of voter behaviour were also studied in order to identify the voter's adherence to the voting instructions. The ballot paper instructed the voter to place "one X in one of the boxes". The number of voters who complied with this instruction were as follows: 76% followed the instructions by placing an X in a single box, 22% placed a tick in a single box and the final 2% placed some other mark or in one case no mark at all on the ballot paper.

4.2.3 Efficiency

An indicator of the time taken to complete the voting session was measured. Efficiency is taken as a measure of whether the voter could cast their vote on the system without unreasonable effort and within a short time. In this context the amount of time that the ballot paper remained on the voting surface was analyzed for each voter. This information is useful because it provides an indication of the ease of usability of the system. Towards that end the start time and end time of each voter session was recorded. The start time began when the voter was handed the ballot paper and the end time when the ballot paper was placed in the ballot box. The average voting time was found to be 75.7 seconds.

5. CONCLUSION AND FURTHER WORK

This paper has presented the 'Dual Vote' system which incorporates a novel user interface. This UI simultaneously records a voter's preference in paper and electronic form. Based on a comprehensive review of modern e-voting systems it has been shown how the Dual Vote system addresses the issues of usability and verifiability, which are largely seen as deficiencies in many modern e-voting systems.

The Dual Vote system was used to facilitate a student union election. A total of 100 out of the 332 voters who voted were surveyed in order to find a SUS score for the Dual Vote system. When compared with the SUS scores of other e-voting systems the Dual Vote system achieved a usability ranking that equalled that of the previously highest ranking system. This is an encouraging result as subjective usability is a significant barrier to acceptability of e-Voting systems.

The overall error rate of the Dual Vote System was found to be 11.4%. This was largely attributed to a faulty prototype electronic pen. When the misclassifications attributed to the pen were excluded, the error rate dropped to 3.9%. These issues are already in the process of being addressed it is expected the system will achieve a significantly reduced error rate in subsequent elections. It is expected that the next refinement of the system will achieve an accuracy rate of 99% or greater.

In the future the objective is to extend the interaction analysis to include other users of the e-voting system such as system administrators. It planned to supplement the current system with a GUI screen that would provide voting related information or interaction options to the user.

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