A Hybrid Touch Interface for Prêt à Voter

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Abstract

In this paper we propose a novel front-end for Prêt à Voter that aims to maintain the privacy and integrity guarantees found in the paper based version, whilst simultaneously improving the accessibility of Prêt à Voter. Namely, we maintain the Prêt à Voter property that no machine learns your vote, whilst providing improved accessibility. We term this new front-end Hybrid Touch and have implemented it on both a Microsoft Surface and a multi-touch screen. Hybrid Touch combines the privacy benefits of paper with the accessibility benefits of a touch screen. It is this combination that provides more accessibility opportunities as well as allowing Prêt à Voter to handle larger and more complicated elections. Our goal is to develop a single unified front-end, which can be easily augmented with additional accessibility technology, to provide the same core interface for both able-bodied and disabled voters.

1 Introduction

The Prêt à Voter [17] end-to-end verifiable voting system combines privacy and integrity guarantees into a familiar paper based voting platform. However, the accessibility of a paper based scheme is quite limiting, particularly when combined with the randomised candidate ordering of Prêt à Voter. In this paper we will provide a summary of the importance of accessibility and some of the constraints faced when looking to trial an electronic voting system in the UK. We will describe the difficulties faced in trying to make a system accessible when using a paper based voting scheme. We highlight the trade off that is often required between accessibility and privacy. In Section

4 we present an approach to providing accessibility, for a limited set of disabilities, whilst maintaining the same privacy and integrity constraints found in traditional paper based Prêt à Voter. We will demonstrate two different implementations of this novel approach we have termed Hybrid Touch. Hybrid Touch combines a paper left hand side with a digitally rendered right hand side to provide the combination of privacy and accessibility. In Section 5 we will discuss our future plans on how we will develop the approach further.

2 The Importance of Accessibility

In the UK there are a number of charities and pressure groups that campaign for accessibility of voting. After each general election they compile the Polls Apart [1] report. This report is included within the UK Electoral Commissions review of the election and provides both an analysis of the current voting system and a view of the future. The 2010 report [18] had a number of interesting points and recommendations. Of note was the conclusion that the government should "Ensure disabled people can vote independently and in secret by diversifying voting methods...". The report highlighted the Governments obligations under the European Human Rights Act and the UN Convention on the Rights of Persons with Disabilities to provide suitable facilities to allow disabled voters to vote with the same privacy and security guarantees afforded to able bodied voters. One of the conclusions in the section on e-voting in [18] was that "Our evaluation concluded that addressing the complexity of these systems, without compromis-

ing security, was where further effort needs to be directed". This is the motivating factor for trying to develop new techniques to allow disabled voters to interact with end-to-end verifiable election systems.

It is recognised that this is a significant challenge. The UK Electoral Commission [2] set out basic requirements for those organisations wanting to trial an electronic voting scheme in 2003, when trials were still being considered, in their recommendations [19]. It set out a number of minimum requirements, the most notable two in this context are:

1. Suppliers should demonstrate they have taken into consideration the specific needs of disabled people when planning and implementing all voting systems

2. User trials with people with a diverse range of impairments (e.g. people with visual, hearing, mobility, coordination and learning impairments) should be conducted

These two points highlight both the importance of addressing accessibility when proposing and advocating end-to-end verifiable voting schemes and the diverse forms of accessibility that need to be addressed. It is often accessibility for the visually impaired that gains the most attention, but the other forms of disability such as mobility, co-ordination and learning impairments are equally important.

2.1 Multiple Voting Platforms

An often suggested solution to the problem of accessibility is to provide multiple platforms for voting, for example, have paper based voting for able-bodied voters and pure touch screen voting for disabled voters. However, there are a number of problems with this approach. Often the more accessible platform has weaker privacy guarantees, for example a touch screen device will learn how the voter has voted. This is in direct contravention of the requirement for disabled voters to be afforded the same privacy and integrity guarantees as able-bodied voters. It also acts to segregate the disabled voters and could even create resentment. If the able-bodied voters are having to use a less accessible, and probably less usable,

scheme they may resent that the disabled voters are able to utilise a different more modern looking system. The segregation of voters into categories also causes problems in how you can determine who does and does not count as disabled and is fundamentally against the concept of providing a single unified interface. Having a single interface may not seem important, but from the perspective of a disabled voter it makes a significant difference. If a disabled voter is able to interact with the same system as everyone else they are genuinely being treated as an equal to able-bodied voters. This provides a sense of value for both themselves and their vote and indicates their equal status within society.

Our goal is to develop a front-end that is fundamentally the same for everyone, but that can be augmented with additional accessibility technology without compromising the privacy or integrity of the underlying voting system.

3 Existing Front-ends

In this section we provide an overview of the traditional paper based front-end that is usually thought of when discussing Prêt à Voter. We describe two alternative front-ends to Prêt à Voter. The touch screen interface described in Section 3.2 can provide good accessibility but it comes at the cost of privacy. Alternatively, the approach described in Section 3.3 makes use of some similar technologies to the ones we use, but does not provide additional accessibility.

3.1 Paper Based Front-end

Prêt à Voter has traditionally been proposed with an all paper front-end [17]. The voter receives a paper ballot, with a perforation down the middle, a randomised candidate order on the left hand side and vote boxes and an onion contained in a 2D barcode[1]

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[1]The exact contents of the onion varies depending on the version of Prêt à Voter and the type of election being run. At an abstract level it should be thought of as containing an encrypted copy of the permuted candidate names. Some version of Prêt à Voter have a single onion for the entire ballot, others have a separate one for each candidate. In the current Prêt à Voter version the encrypted contents of the onion are
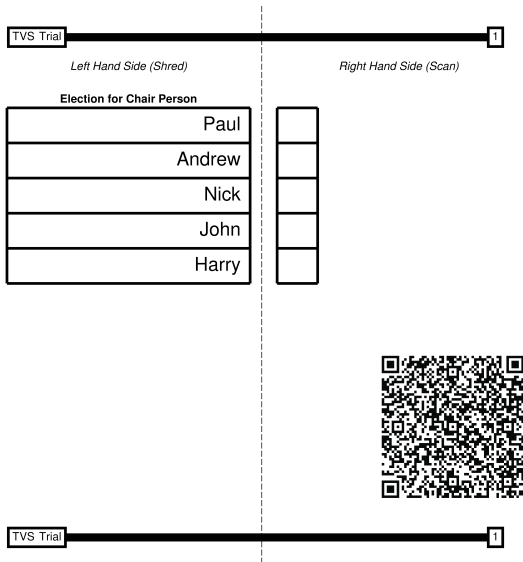
Figure 1: Example Prêt à Voter Ballot (the dashed line represents the perforation)

on the right hand side. An example ballot can be seen in Figure 1. The voter fills in the right hand side with their vote, tears down the perforation, destroys the left hand side and has the right hand side scanned. The contents of the right hand side are submitted to the Web Bulletin Board, which provides a receipt to prove to the voter that their vote has been accurately recorded. One of the appealing features of this approach is that no machine learns how the voter has cast their vote. Once the left hand side is destroyed the scanner is unable to tell whom the vote was for due to the randomised candidate ordering. However, the all paper front-end does have a number of drawbacks. Firstly there is the practicality and feasibility of accurately reading the filled out vote. This is reasonable to do for a First Past the Post (FPTP) election, since the domain of detection is very narrow; is there an "X" or not. However, when used for

ranked elections the task is considerably harder. The scanner must now accurately recognise handwritten numbers. Whilst recent research has shown improvements in handwritten number recognition [7], they still cannot offer a 100% accuracy rate. The viability of applying such techniques is uncertain and even a small percentage of errors could create serious bottlenecks in the polling station and possibly even undermine the trust in the system. Strategies for mitigating this can be employed, for example, having a touch screen to confirm what has been scanned in, but this raises questions over what the binding vote is: the vote on the paper or the vote submitted from the screen? It adds an additional check to the process, which is essential, and leads to the voter having to check their vote on multiple occasions, once when scanned, once on the returned receipt and then again at home on the Web Bulletin Board. It seems unlikely that significant numbers of voters are going to undertake this additional workload.

The greatest problem with the paper only front-end is the lack of suitable accessibility technologies. Accessibility is not just a desirable property for an election system to have, it is often a requirement. In the UK, proposed systems must demonstrate a plan to provide accessibility before the Electoral Commission will even back the running of a trial with it [19]. With an all paper front-end we are in the unfortunate position of producing a system that is less accessible than the current paper voting system used today in the UK. Whilst the current system fails on many areas of accessibility, it does handle accessibility for the visually disabled, albeit in a crude manner. Currently, a person with a visual disability can request the use of a template. This is a metal or plastic template that is attached to the top of the ballot paper. The template has the names of the candidates in raised typography and then a corresponding flap to open to allow the voter to mark their "X" in the appropriate box. There are a number of problems with this simple form of accessibility, particularly in terms of the practicality of attaching and detaching the template. There are also privacy concerns with regard to detaching the template from a completed ballot. However, even though it is a poor form of accessibility, due to the randomised candidate ordering

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not stored on the ballot form itself, due to size restrictions of the 2D barcode. As such, the encrypted data is committed to the Web Bulletin Board and bound to the serial number. The contents of the barcode on the ballot is a digitally signed copy of the serial number.

in Prêt à Voter this is would no longer work. This could become a hurdle to running a trial of Prêt à Voter in the UK, or elsewhere, and it is this we aim to start addressing in this paper.

3.2 Touch Screen Front-end

There have been a number of Prêt à Voter designs which have advocated various forms of Touch Screen front-ends [8],[9]. Whilst the exact details of the voting protocol and ceremony vary, they rely on the machine that the voter uses to construct their vote to also protect the secrecy of the vote and thus the voters privacy. More recently, a compromise has been proposed that utilises an Electronic Ballot Marker, whilst maintaining the scanner and thus providing a buffer between the two components. However, at the root of all these systems the voter must trust at least one device not to breach their privacy, due to at least one machine learning how they vote. This may be a perfectly reasonable compromise to make in practice and be acceptable to the electorate. The advantage of this approach is that it provides excellent accessibility opportunities because the machine learns everything and thus can provide a wide range of assistance in casting a vote. There are generic front-end systems, for example, the Prime III [6] system that provide excellent accessibility. However, this comes at the cost of privacy, which we view as being a significant compromise. The real challenge is in trying to find a scheme that does not compromise on privacy whilst simultaneously providing accessibility.

3.3 Dual Vote Front-end

There are numerous different verifiable voting systems with different front-ends, [4][16][3] are just a few, of most relevance to this paper is the Dual Vote interface described in [10]. The novel interface in [10] combined a standard looking paper ballot with an inductive sensor array and a special pen. The voter would cast their vote on the paper and simultaneously it would be digitised and submitted to the system. This removed the need for any form of scanning step and made the digitisation of the vote completely invisible to the voter. The advantage of this approach was that it maintained the existing voting method whilst seamlessly augmenting it with electronic recording. Their work was further developed in [12]. More recently, in [11], a preliminary study on combining Dual Vote and Prêt à Voter is presented. The fundamental concept remains the same, in that the vote choice is collected passively and the voter still completes their vote by marking their choice on the right hand side of the ballot. This improves the usability of Prêt à Voter, however, the system still makes use of an all paper ballot, thus it has the same accessibility limitations of traditional Prêt à Voter, as described in Section 3.1.

In contrast to Dual Vote our aim is to remove the need to fill in a piece of paper to cast the vote. We believe replacing the paper right hand side with a purely digital right hand side allows a wider range of accessibility equipment to be used. It also allows for real time help and feedback to be given to the voter via the underlying screen. There are some similarities in technology, the Dual Vote approach uses either metallic strips on the underside of the ballot to allow it to be detected on the inductive sensor array reader in [10] and [12], or optical markers printed on the underside for the system described in [11]. This is analogous to the conductive pads we will describe in Section 4.3 and the Identity Tag used by the Microsoft Surface described in Section 4.2. One of the challenges we faced was in developing techniques that worked with either a touch screen or Surface Computer. We required the ballot to be detected when placed onto the Touch Screen or Surface Computer, thus allowing us to render the digital right hand side accordingly. The Dual Vote approach did not need to operate on top of a screen because it maintained an all paper ballot and was therefore able to use dedicated hardware to detect the location of the ballot.

4 Hybrid Touch Interface

In this section we introduce the Hybrid Touch concept and then detail two possible ways of implementing such an approach. This aims to make a significant step towards addressing the accessibility weaknesses of Prêt à Voter, whilst maintaining the same

privacy guarantees. As was mentioned in Section 3.1 there are practical issues with a paper based Prêt à Voter scheme when used for ranked elections. Whilst the proposed scheme focusses on the accessibility opportunities it presents, it simultaneously addresses the issue of how to accurately capture ranked votes for able-bodied voters. In this paper when we use the term "touch surface" we are referring to the touch sensitive area of both the Microsoft Surface and the Touch Screen.

4.1 The Concept

The fundamental concept of Hybrid Touch is to combine the privacy properties of paper with the accessibility properties of a touch screen. As such, we keep the left hand side of the ballot as a piece of paper, but render the right hand side digitally. One possible idea was to require the voter to align a piece of paper to a screen to enable something similar. However, such approaches are by their very nature not particularly accessible and there are question marks over whether it is even usable for an able-bodied voter. With Hybrid Touch the touch surface detects the location of the left hand side when it is placed on it and renders the right hand side in the correct location and orientation. If the left hand side is moved around the touch surface it can be tracked and the location of the digital right hand side updated accordingly.

The vote is entered via the touch surface and as such allows us to augment the system with accessibility technology to provide easier interaction. The machine is able to give step by step instructions and ensure that a valid vote is being cast, whilst still not being able to learn who the vote is for. This provides one of the fundamental goals of accessibility in that both able-bodied and disabled voters both use the same interface and are afforded the same privacy guarantees. Due to the vote being submitted via the touch surface we can provide additional functionality. For example, when an external accessibility control is utilised the system can change to a mode whereby a selection cursor is moved between the various vote boxes. Therefore, instead of requiring the voter to use the touch surface they can interact via large tactile buttons to move the cursor across the digital

right hand side to make their selection. This also enables voice control, sip and puff and many other forms of accessibility technology that can currently be attached to a PC.

The advantage of the system is that the voter need only place the left hand side onto the touch surface and the right hand side will be appropriately rendered. There is no alignment needed or complex instructions to follow. Step by step guides can help lead a voter through the process to ensure they complete their ballot in a valid manner. If multiple elections are taking place the voter can be given multiple left hand sides for different races, which they can complete in any order.

In summary, the features of the system are as follows:

- The same privacy and integrity guarantees offered by standard Prêt à Voter are maintained;

- The presence, location and orientation of a left hand side can be accurately detected;

- The digital right hand side can be rendered on the touch surface, correctly aligned to the left hand side;

- Movement of the left hand side can be tracked and the right hand side re-rendered accordingly;

- A voter can enter their vote by interacting with the digital right hand side, through the touch surface or via external accessibility equipment.

4.2 Microsoft Surface Implementation

The concept originated from looking at the capabilities of a Microsoft Surface and as such it was our first implementation platform. Our development has focussed on Version 1 of the Microsoft Surface, as seen in Figure 2. Version 2 of the Microsoft Surface started shipping at the beginning of 2012 and provides some exciting new developments. There have been significant improvements in the underlying technology, which we will discuss later, but the concept is fundamentally the same. Details of how Version 1

of the Microsoft Surface works can be found in [15] with further details of Version 2 in [14].

Figure 2: Photo of Microsoft Surface (Image from [14])

Figure 3: Diagram of Surface Computer (Diagram from [15])

Version 1 of the Microsoft Surface uses infra-red emitters and cameras to detect touches and objects placed on it. A high resolution projector is used to display a screen onto the underside of the surface, as depicted in the diagram in Figure 3. To detect objects, Microsoft provides a type of 2D barcode called an Identity Tag. These allow the surface cameras to both extract a 128-bit data value from the tag as well as calculate its location and orientation.

On the back of the left hand side of the ballot we print a custom Identity Tag. An example of such a tag is seen in Figure 4. This contains the serial number, as in the current 2D barcode that would normally be found on the right hand side of a standard Prêt à Voter ballot [17]. This also identifies the race and election the left hand side is for and provides the system with information about the type (FPTP, Single Transferable Vote) and number of vote boxes to display on the digital right hand side. The Identity Tag returns location and orientation information to the system so the right hand side can be appropriately positioned. The digital right hand side then responds to touches to allow the voter to cast
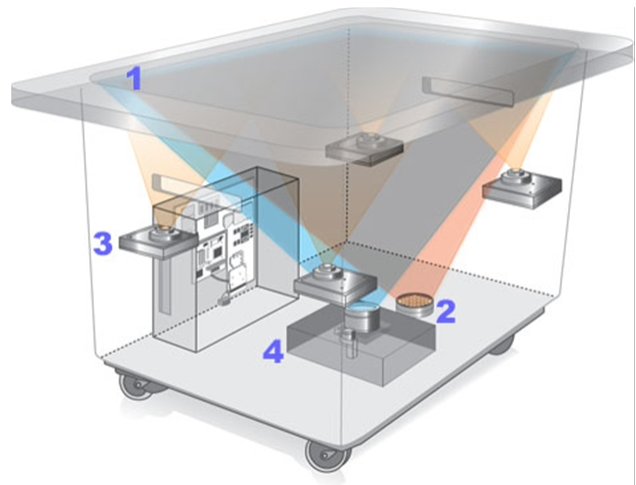
their chosen vote. Additional accessibility equipment can be attached to the Microsoft Surface to handle alternative ways of interacting with the digital right hand side. The Microsoft Surface contains a standard desktop PC running Microsoft Windows. As such, any accessibility equipment that can be connected to a standard PC can be connected to a Microsoft Surface. The background of the Surface displays instructions and help information, as well as guiding the voter through the vote casting process. It can for example warn the voter when they have cast a valid, but incomplete vote. For example, if they have provided the minimum number of rankings to make the vote valid, but not a full ranking. If the voter removes the left hand side from the Surface the digital right hand side fades away, but is remembered until the voter submits their entire ballot. As such, the voter can place the left hand side back on the Surface and their previously filled in digital right hand side will be displayed. This allows the voter to go back through and verify or modify their vote. It is also possible to simultaneously have two or more left hand sides placed on the Surface and still interact with the respective right hand sides. This allows Prêt à Voter to handle more complex and longer elections

which may consist of many races or referendums in a single election. This previously would have been hard to manage with individual ballot onions and multiple scans and receipts.
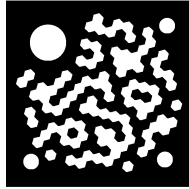

Figure 4: Example Identity Tag

Figure 5: Photo of the system running on a Microsoft Surface

In Figure 5 the system can be seen running on a Microsoft Surface. In the example provided two left hand sides can be seen, the one on the left is a FPTP race, whilst the one on the right is a ranked election. Two buttons can be seen towards the bottom of the surface display, the one on left allows a voter to reset their ballots and the one on the right allows the voter to cast their ballot. The text along the bottom provides feedback and guidance and displays any warnings or errors when trying to cast a ballot. Figure 6 provides an alternative view of the same surface. This makes it clearer to see the status information on the right hand side of the Surface that gives real time feedback on the progress of the voter through the voting procedure.

The system was implemented in C# using the Windows Presentation Foundation (WPF). Initially it was tested using the Surface SDK Simulator, but was later deployed and tested on an actual Microsoft Surface, as shown in Figure 5 and 6. One of the downsides of the Microsoft Surface is the cost. Version 1 cost in the region of £10,000 and Version 2 in region of £8,000. It was thus beyond our budget to purchase our own Microsoft Surface for the experiments. We are grateful to Thales Research and Technology in Reading for providing us with access to their Microsoft Surface. Whilst the cost seems high, this is still a developing technology and it is believed the costs will fall as the technology becomes more widespread.
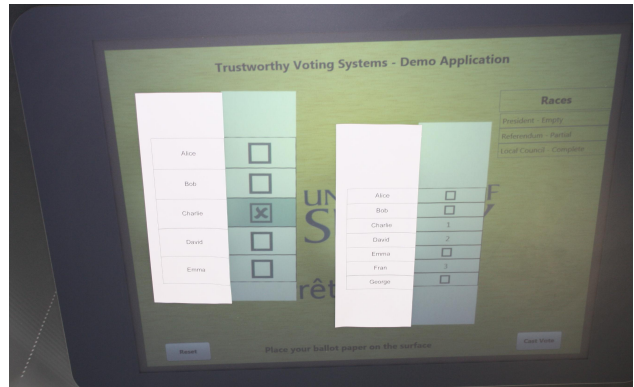

Figure 6: Alternative perspective of the system running on a Microsoft Surface

4.2.1 Microsoft Surface Version 2

Version 2 of the Microsoft Surface presents some exciting new opportunities. Despite the significant changes in the underlying technology our approach will continue to work on the new hardware. The most significant change has been the integration of the camera into the display using a technique referred to a PixelSence$^{\text{TM}}$[13]. Further details about the new version can be found in [14]. One of the advantages of this new approach is that the Surface is now just 103mm thick, thus making it easier to mount on an arm to easily adjust the height to make it more accessible.

4.3 Touch Screen Implementation

We also explored the possibility of using Touch Screen technology to implement the same concept as we had done on the Microsoft Surface. In early 2010 3M launched the M2256PW, a 22 inch projected capacitance monitor, capable of registering 20 simultaneous touches (the screen is able to register more touches, but is not officially rated as such). Our approach was similar to the one employed for the Microsoft Surface, except instead of using a 2D style barcode (Identity Tag) we would simulate touches in a predefined pattern. When the system detects the presence of such a pattern it can use the touch locations to locate and orientate the left hand side and then render the right hand side in the appropriate location on the screen. In this section we provide a brief summary of how the touch screen works and how we simulate the touch points.

4.3.1 Projected Capacitance

The 3M screen, much like most modern touch screens, uses projected capacitance technology. Projected capacitance works by having a matrix of conductive rows and columns etched on the screen. When a conductive object is placed on the screen, for example a finger, it disturbs the local electrostatic field at that point. This disturbance can be measured and thus the touch detected. Their are two forms of projected capacitance, the one provided by the 3M screen is

Mutual Capacitance. This works by placing a capacitor at the intersection of each row and column and applying a voltage to the rows and columns. This works by exploiting the fact that when two conductive objects are placed very close to each other they are capable of holding a charge. When a finger or conductive stylus is placed on the screen it disturbs the electrostatic field which alters the mutual capacitance. Due to having an independent capacitor at each intersection it allows very accurate measuring of the location of the touch point and also multiple simultaneous touches. The alternative to Mutual Capacitance is Self Capacitance, which has the same matrix except the rows and columns operate independently instead of the intersections. When a finger is placed on the screen the capacitive load of the finger is measured by an amp meter. This provides a stronger and more reliable detection of a single touch, but due to the nature of it operating on a column and row basis it cannot easily handle more than one touch due to ghosting. There have been some attempts at sophisticated algorithms to allow two touches to enable the use of gestures, but this would still be insufficient for our intended use.

4.3.2 Simulating Touches

The primary difficulty we faced is how to simulate a touch with a passive piece of paper. The human body is a very effective capacitor that can easily hold a charge and thus the touch screen is tuned to respond to that. Thus we need to simulate not just a touch, but a human touch. We could have looked at trying to develop custom hardware but this would have been prohibitively costly and would result in any developed system not being able to exploit the falling prices of off-the-shelf touch screen hardware. Some touch screens provide a stylus that can interact with the screen, but these are usually either metallic, and thus use the human body as a capacitor, or have a capacitor built into them. As such, they were not directly applicable to our goal of modifying a piece of paper to act as a touch point. We experimented with a number of approaches during our testing and found the most reliable was a piece of foil backed card with cubes of capacitive foam attached as feet.

Capacitive foam is used in the electronics industry to protect sensitive components when being transported or worked on. The foil backed card was large enough to hold a sufficient charge to simulate 4 touch points. However, we needed to use the foam feet to both simulate the shape of a finger and to prevent the rest of the card creating spurious touch points when within close proximity to the touch screen. A image of a the underside of the foil backed card, complete with capacitive foam pads can be seen in Figure 7
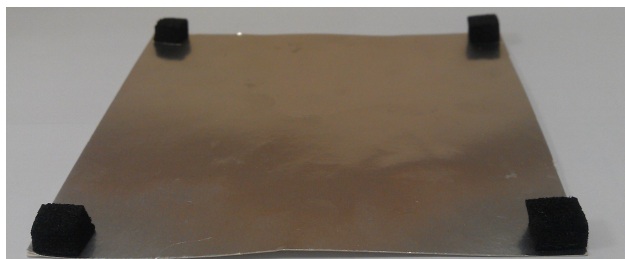

Figure 7: Underside of foil backed card with conductive foam pads

Ideally we would like to construct something that can provide the necessary capacitance in a space no larger than a finger tip. This would allow us to use standard card instead of the foil backed card and mean we did not need to keep the foil backing away from the touch screen. It should be noted that due to the nature of mutual capacitance even if a cover was placed over the foil backing the electrostatic field would pass through it and thus the only way to prevent the spurious touches is to provide a large enough gap between the foil and the screen.

4.3.3 Implementation

The system was implemented using the Java MT4j Library [5] to detect the touch points. The Java algorithm examines the touch points detected and calculates if they fit the predetermined template for a left hand side. If they do, the right hand side is then rendered in the appropriate location, as shown in Figure 8. As the left hand side is moved around on the screen the touch points update and the rendered right hand side is updated accordingly. We are therefore able to mimic the same left hand side tracking as the Microsoft Surface, however, we do not currently have a way of getting the serial number from the left hand side. This could be done by having an external barcode reader. However, we believe that with the use of a sparse matrix of up to 14 simulated touch points, on the back of the ballot paper, would provide enough capacity to encode the serial number and still leaving plenty for left hand side orientation and touch interaction.
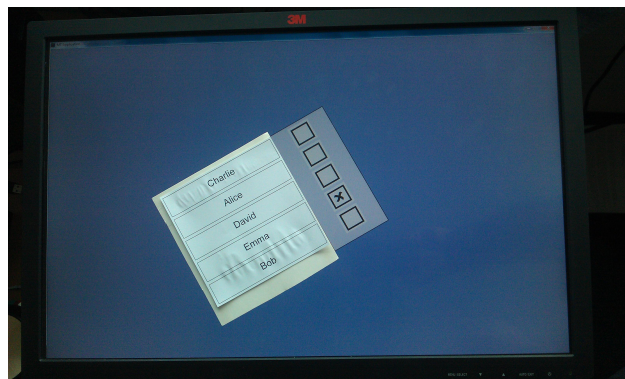

Figure 8: Photo of the system running on a 3M Multitouch screen

4.4 Voting Ceremony

The underlying concept is the same for both the Touch Screen and Microsoft Surface implementation. From a user perspective there is no difference. As such, the voting ceremony described below is applicable to both implementations, as is the analysis in Section 4.5 and Section 4.6. The envisaged voting ceremony would proceed as follows:

- The voter is issued with a suitable left hand side

- The voter places the left hand side anywhere on the screen or surface

- The voter enters their vote and then selects the cast option on screen or surface

- The voter destroys the left hand side

- The vote is submitted to the WBB and the returned receipt is printed for the voter

All the equipment required for voting is located within the polling booth itself, once the voter has hit the cast button and received their receipt, thus confirming it has successfully been recorded onto the WBB, they have completed the vote casting and can leave.

4.4.1 Ranked Elections

When voting in a ranked election the voter selects the candidates in order of preference. Thus, the first box they press receives the preference "1", the second receives "2" and so on. There is an "Undo" button that allows a voter to remove the last preference if they have made a mistake or wish to make a change. There is also an option to reset the ballot form if they wish to start again.

4.4.2 Auditing

The auditing process is similar to traditional Prêt à Voter. The information contained within the IdentityTag, or barcode/spare matrix, is sufficient to request an audit. In Prêt à Voter, the signed serial number is all that is required to request an audit. This triggers a decryption of the candidate ciphers and the printing of an audit receipt. An able-bodied voter can check this receipt in the normal way they would with standard Prêt à Voter. Currently we don't have a way of printing a fully accessible receipt. The primary difficulty is how to make it accessible to visually impaired voters. There is scope for using a Braille printer, but this could be expensive. The advantage we have is that the receipt, both for audit and voting, does not reveal any secret information. As such, a disabled voter, who is unable to check their receipt themselves, can request someone else to check it for them, without fear that they will reveal how they voted or any secret information.

4.4.3 Ballot Form and Receipts

The example ballot forms shown in the sample images do not contain serial numbers, race names or election instructions. Ballots used in a real election would look like the left hand side of a standard Prêt à Voter ballot. They would contain a plain text serial number on the left hand side as well as instructions and races names. The standard procedure for checking the receipt that is printed out should be followed, for both auditing and voting. The voter should check that the signed contents contains the same serial number as is shown on the ballot and in the case of a submitted vote, that it correctly reflects their preferences or selection. As such, the Idenity-Tag, or barcode/spare matrix, does not need auditing directly, since it is audited via the standard auditing procedure.

4.5 Who could use the system

As was mentioned in Section 4 the proposed approach is a first step towards an accessible system. As described, we believe this system could be used by a range of disabilities. The interactive nature is of clear benefit for those with learning difficulties since the system can carefully guide them through the system, with the help of audio prompts. It can ensure that they do not unintentionally spoil their ballot. It is also suitable for those with limited mobility. Provided the voter is capable of removing the left hand side from an envelope and placing it onto the surface of the monitor or Microsoft Surface they can then interact via additional accessibility equipment if needed. There is scope for using the system with visually impaired voters as well. Large print ballots can be easily accommodated by have an indicator included within the serial number so the system can react accordingly and render a larger virtual right hand side. This would not breach privacy or integrity of the vote. Embossed printing or Braille could be used on the left hand side with tactile buttons used to interact with the system. Audio feedback could be given to provide the voter with assistance in casting their vote. The audio feedback is limited to the actions being undertaken on the right hand side, for example,

which vote box is currently selected, what the next preference is, when the ballot is complete, etc. The audio feedback does not provide information on what is contained in the left hand side, since the machine does not learn this. As such, the voter must interact with the left hand side via Braille or embossed type. It should be noted that for those visually impaired the verifiability does become harder, since the receipt would need to be constructed in a way that can be consumed by the voter. The cost and complexity of having an embossing printer or even Braille printer in every polling station may prohibit this.

4.6 Security

The underlying security of the system remains unchanged from that in traditional Prêt à Voter, as found in [17]. This is because the left hand side remains on paper and is thus secret from the machine. It is acceptable for the machine to learn the contents of the digital right hand side because it would do so in traditional Prêt à Voter. The right hand side becomes a matter of public record when it is recorded and is made accessible on the publicly accessible Web Bulletin Board. The right hand side can be made public because it does not reveal how the vote was cast due to the randomised candidate ordering. When using the Microsoft Surface approach there are some concerns that the use of IR cameras to detect the touches and Identity Tag objects is a potential privacy concern. This is only a privacy concern if the protocol is not followed, for example, the voter places the ballot face down on the surface instead of face up. This is equivalent to the voter not destroying their left hand side and then showing it to a poll worker. It is also important that a suitable thickness of paper is used for the left hand side. Our tests have shown that standard A4 paper is of sufficient thickness to prevent the IR cameras seeing through it. The Surface provides a direct access mode for viewing the camera feeds, as such the selected paper should be tested prior to use in a real election. This is not a problem that is encountered with the alternative touch screen approach, described in Section 4.3, since no cameras are utilised. Although, both approaches are still dependent on the destruction of the left hand side.

5 Future Work

The future work is split into two areas; technical and evaluation. There are some technical aspects that need further work to make them feasible for use in a large scale. Primarily how the left hand side can be augmented with the conductive material to allow it to be detected by the multi-touch screen. We are investigating a number of different avenues at the moment including conductive inks and paints that could be easily applied. Once we have a more robust way of constructing the left hand side we will develop the sparse matrix to allow an identifier to be read and thus the vote submitted without needing additional barcodes or barcode scanning.

Once a more polished system is available we want to demonstrate it to disability groups, in particular those involved in the Polls Apart Campaign, and get their feedback on how it can be improved and developed further. We recognise that there is still development work to handle a wider range of disabilities and this will form part of our overall ongoing research.

There has been significant developments in Tablet based computers, with improved touch screens and processing performance. From a technical standpoint, the multi-touch approach presented in Section 4.3 could work on high end tablets that provide a mutual capacitance touch screen. The challenge is getting access to the low level touch data, which is typically hidden by the development frameworks and operating systems present on tablets. The other consideration would be whether the size of the screen is sufficient to provide a good user experience. The ballot would need to be small to still provide a meaningful area for user interaction. However, the fact that this technology is becoming more widespread is a further motivation to develop the approach discussed in Section 4.3 to provide the option of using tablet devices as well.

6 Conclusion

In this paper we have presented a novel front-end design for Prêt à Voter that maintains the same levels of integrity and privacy as is offered by the all pa-

per interface, whilst improving the accessibility of the system. We have developed techniques to locate and orientate a paper left hand side placed on a touch surface. This allows us to render a digital right hand side seamlessly in the appropriate location, to produce a hybrid paper and digital ballot. This has required the use of Touch Screen and Surface Computing technology in a novel way. We have prototyped the proposed scheme on both a Touch Screen and Microsoft Surface, thus providing proof of concept, and demonstrating on a practical level that it can be realized. We have highlighted the benefits of this approach for both able-bodied voters and in terms accessibility. The proof of concept demonstrates a single unified front-end that can be used by both able-bodied voters and a range of disabled voters.

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