



University of Glasgow | School of  
Computing Science

## HandiVote Mobile Application for Referenda on Economic Decisions

Tsvetelina Valcheva, 0904869v

School of Computing Science  
Sir Alwyn Williams Building  
University of Glasgow  
G12 8QQ

March 22, 2013

## **Abstract**

Current academic work on electronic voting and practical experience from various countries does not provide a satisfactory solution to the problem of anonymous, simple and verifiable electronic voting. Moreover, none of the current implementations support multidimensional voting.

In the conditions of economic recession, national budgetary issues often feature in the public domain. HandiVote is an electronic voting system for facilitating traditional and budgetary referenda and supports voting via multiple channels. The HandiVote system allows for meaningful budgetary referenda that incorporate questions on both spending and taxation adjustments. The system optimises inconsistent votes subject to budget constraints using an algorithm validated with real UK data. Compared to paper ballot voting, HandiVote allows for higher accessibility to voting, encourages participation thanks to time and location independence and is more cost effective.

The solution, proposed here, is the implementation of HandiVote as a web mobile application, a choice justified by the rising popularity of mobile devices and the advances of web development technologies. The system is implemented as open source software to encourage reuse.

Two evaluations of HandiVote were conducted including one traditional and one budgetary referendum. User feedback in the form of surveys and qualitative interviews verified the usability of the system. Two additional polls, conducted on request, further demonstrated the ease of use and wide-spread application of the system. The evaluations tested multiple voting channels including voting via HandiVote's web interface for mobile devices and desktops, voting via SMS and lastly easing navigation voting by scanning a QR code.

Overall, it is evident that the problem of accessible electronic voting on budgetary issues is a highly relevant topic, as some of the work presented here formed part of an academic paper [18, 19] and another paper currently under review [78].

## Education Use Consent

I hereby give my permission for this project to be shown to other University of Glasgow students and to be distributed in an electronic format. **Please note that you are under no obligation to sign this declaration, but doing so would help future students.**

Name: \_\_\_\_\_ Signature: \_\_\_\_\_

# Contents

<b>1</b>	<b>Introduction</b>	<b>1</b>
1.1	Problem Overview . . . . .	1
1.2	Aims . . . . .	1
1.3	Motivation . . . . .	2
1.3.1	Why do we need referenda? . . . . .	2
1.3.2	Why do we need to be able to vote on economic decisions? . . . . .	2
1.3.3	Why should we vote on mobile devices? . . . . .	2
1.3.4	Why we need a better, more transparent electronic voting? . . . . .	4
1.4	Report Outline . . . . .	4
<b>2</b>	<b>Related Work and Background</b>	<b>5</b>
2.1	Electronic Voting Requirements and Process . . . . .	5
2.2	Related Academic Work . . . . .	6
2.3	Country Experience with Electronic Voting . . . . .	8
2.4	Referenda on Economic Decisions . . . . .	11
2.5	Background Review Implications . . . . .	11
2.6	HandiVote - Accessible, Verifiable, Anonymous Voting . . . . .	12
2.7	Web Based Extension . . . . .	12
2.8	Conclusion . . . . .	13
<b>3</b>	<b>Design and Implementation</b>	<b>14</b>
3.1	Requirements . . . . .	14
3.1.1	Functional Requirements . . . . .	14

3.1.2	Finding Feasible Referendum Outcome Subject to Budget Constraint . . . . .	16
3.1.3	Non-functional Requirements . . . . .	16
3.1.4	Survey on Mobile Phone Usage . . . . .	17
3.2	Design . . . . .	17
3.2.1	Architecture . . . . .	17
3.2.2	Voting Process Design . . . . .	18
3.2.3	Administration Process Design . . . . .	19
3.3	Security . . . . .	20
3.4	Implementation . . . . .	21
3.4.1	Implementation Technologies . . . . .	21
3.4.2	Database Design . . . . .	21
3.4.3	Voter Interface . . . . .	22
3.4.4	Administrator Interface . . . . .	23
3.4.5	Cross-Cutting Files . . . . .	25
3.4.6	Problems . . . . .	26
3.5	Testing . . . . .	26
3.6	Conclusion . . . . .	26
<b>4</b>	<b>Evaluation</b>	<b>27</b>
4.1	Non-budgetary Evaluation . . . . .	27
4.1.1	Aims . . . . .	27
4.1.2	Running the Evaluation . . . . .	27
4.1.3	Results . . . . .	28
4.2	Budgetary Evaluation . . . . .	29
4.2.1	Aims . . . . .	29
4.2.2	Running the Evaluation . . . . .	30
4.2.3	Results . . . . .	30
4.3	Staff Common Room Poll . . . . .	31
4.4	North Kelvin Meadow Community Poll . . . . .	31

4.5	Discussion . . . . .	31
4.6	Conclusion . . . . .	32
<b>5</b>	<b>Discussion and Conclusion</b>	<b>33</b>
5.1	Discussion . . . . .	33
5.1.1	Usability . . . . .	33
5.1.2	Limitations . . . . .	33
5.2	Future Work . . . . .	34
5.2.1	Flexibility and Configurability . . . . .	34
5.2.2	Security . . . . .	34
5.2.3	Scalability and Availability . . . . .	34
5.2.4	Accessibility . . . . .	34
5.2.5	Larger Scale Evaluation . . . . .	35
5.3	Personal Reflection . . . . .	35
5.4	Conclusion . . . . .	35
5.5	Acknowledgements . . . . .	35
	<b>Appendices</b>	<b>41</b>
<b>A</b>	<b>Acknowledgement of Sources</b>	<b>42</b>
A.1	Images . . . . .	42
A.2	Code . . . . .	42
<b>B</b>	<b>Use Case Diagrams</b>	<b>43</b>
<b>C</b>	<b>Survey on Mobile Phones Usage</b>	<b>46</b>
<b>D</b>	<b>Evaluation 1</b>	<b>48</b>
D.1	Survey . . . . .	50
<b>E</b>	<b>Evaluation 2</b>	<b>54</b>
E.1	Transcript Interview 1 . . . . .	56
E.2	Transcript Interview 2 . . . . .	57

<b>F</b>	<b>Example Calculations with UK data</b>	<b>59</b>
<b>G</b>	<b>HandiVote Screenshots</b>	<b>61</b>
<b>H</b>	<b>Test Cases</b>	<b>68</b>
<b>I</b>	<b>HandiVote Installation and Configuration Instructions</b>	<b>69</b>
<b>J</b>	<b>HandiVote User Guide</b>	<b>70</b>
	J.0.1 Logging in the Administration Dashboard . . . . .	70
	J.0.2 Creating a referendum . . . . .	70
	J.0.3 Starting the referendum . . . . .	73
	J.0.4 Calculating results . . . . .	75
	J.0.5 Publishing the referendum . . . . .	75
	J.0.6 Deleting a referendum . . . . .	75
	J.0.7 Stopping a referendum . . . . .	76
	J.0.8 Adding an admin . . . . .	76
	J.0.9 Voting . . . . .	77
	J.0.10 View referendum . . . . .	77
<b>K</b>	<b>Status Report</b>	<b>78</b>
	K.1 Overall Status . . . . .	78
	K.2 Major Deficiencies . . . . .	78
<b>L</b>	<b>Summary Log</b>	<b>79</b>

# Chapter 1

## Introduction

*“Voting technology and ballot design can influence election outcomes, affect how voters feel about their ability to exercise their right to vote, and influence voters’ willingness to accept the results of an election as legitimate.”*

– Bederson et al [8]

### 1.1 Problem Overview

Internet and mobile technologies have changed the way we conduct our daily lives. Political and economic information is obtained and discussed online and on the go. We have witnessed how potent electronic media and smart phone technology are in mobilising the public - from the Arab Spring and the London Riots to the 2011 national election in Nigeria, where voters used their phones to report fraud and violence at the polling stations [36]. If more voters among the general and especially the younger public are to be encouraged to participate in referenda, a more modern and flexible voting process is needed.

### 1.2 Aims

The aim of this project is to implement and evaluate a mobile web application version of the HandiVote electronic voting system. A mobile web application is one that is accessible via internet-enabled mobile devices such as smartphones and tablets. By virtue of being web application, the system will be accessible via any browser. The application will also support voting via SMS, thus giving owners of traditional feature phones access to mobile voting. The HandiVote system will allow voters to participate in 3 types of referenda:

- Classic binary (yes / no) referenda such as *“Should Scotland be an independent nation?”*
- Referenda with multiple predefined alternatives such as the Swedish nuclear power referendum, where voters had to choose between 3 proposals for the fate of their nuclear reactors [84];
- Referenda with multidimensional alternatives - a referendum on the national budget could subject multiple issues to vote: for example adjusting government spending on health, education and military.



## 1.3 Motivation

### 1.3.1 Why do we need referenda?

Referenda are arguably one of the purest forms of democracy as they give citizens the authority to provide input into and influence political decisions that concern their well-being without having to rely entirely on the integrity and judgement of their elected representatives. Despite the simplicity of the concept and the benefits for the public, referenda are a rather uncommon occurrence, as governments consider them expensive and time consuming to run [27]. However, the economic crisis of 2008 increased mistrust in the elective representatives system, which brought direct democracy to the spotlight. Lately Iceland voted on a referendum for a new constitution that allows 10% of voters to initiate a referendum [69].

### 1.3.2 Why do we need to be able to vote on economic decisions?

The recent economic crisis directed public attention towards the way governments manage their finances. The UK government's debt reduction programme and budgets as well as the Bank of England's monetary policy are leading topics in the media and impact various indicators from stock prices to government borrowing costs and the UK credit rating. It is clear that in this environment of increased public awareness of economic issues and reduced trust in the way governments handle these, a form of direct democracy that elicits the public opinion is needed. We saw an example of this in the recent US elections, where the state of California voted on increasing the income tax level [53].

### 1.3.3 Why should we vote on mobile devices?

A referendum that enables participation through a mobile device has a number of benefits over traditional paper ballot referenda:

1. *More cost effective* – Voting via a mobile device is significantly cheaper to organise than traditional voting as no paper ballots need to be printed, government staff does not need to be paid to oversee the voting and count the results and no premises or equipment are needed [37].
2. *Higher accessibility* - voters with mobility disabilities who would otherwise find it hard or impossible to participate in the voting are given the opportunity to do so. The same is true for voters living abroad who otherwise might have to travel between cities to the nearest polling station. Removing time and place restrictions has been found to increase the intention to vote [83].
3. *Higher participation* - This follows from the above argument; Moreover, voters that might otherwise find it not worth their time and effort to travel to the voting location are more likely to participate;
4. *Time and location independence* – The recent example of the 2012 Libyan elections where voters were lining up for hours in front of the polling stations in order to place their vote before the closing time [39] is the kind of voter determination that mobile voting does not need to depend on. Voting can take place from any location, at any time.

Generally, lower barriers to participation are desirable to encourage significant turnout on referenda as these could be much more frequent than elections. As Storer and Duncan point out in [73] low turnout in elections and referenda is one of the main drivers for considering the introduction of remote electronic voting in UK. The high demand for postal voting, despite its lack of security, shows that voters would like to be able to vote remotely in

their own time. The Swiss experience with e-voting from 2004 shows that many people that would have voted by post, used the web voting system instead [38]. More importantly, young voters, who would usually abstain, voters from isolated rural areas and voters living abroad all favoured the Internet voting system over any other form of voting [38]. Attracting younger voters is a particular priority in UK, as only about 40% of the 18 to 24 age group participate in elections [77] and voters aged 16 and 17 will be allowed to vote in the upcoming Scottish Independence Referendum.

The HandiVote system has been designed to be accessible to the vast majority of the population.

1. *The HandiVote mobile application is accessible to owners of internet-enabled mobile devices.*

Such devices include feature phones equipped with a browser, smart phones, tablets, eReaders, personal digital assistants (PDAs). As of 2011 there are 1.2 billion mobile web users worldwide [62] with an annual rate of growth of 60% [62, 28]. The mobile broadband subscribers in UK are 42 million[62, 61]. What is more striking is that in many developing countries larger proportions of the population access the internet only via a mobile device and do not use desktop PCs [62, 67]:

<b>Percentage of mobile Web users who never or infrequently use the desktop Web (December 2010):</b>	
<b>Country</b>	<b>Percentage mobile-only</b>
Egypt	70%
India	59%
South Africa	57%
Ghana	55%
Kenya	54%
Nigeria	50%

Table 1.1: Source: On Device Research [67] via mobiThinking [62]

At the same time the prices of mobile broadband services (data plans) are falling significantly [65] making connecting to the internet via a mobile device as affordable as making calls. The general population is now increasingly using their mobile devices to shop online, to pay their bills and to access their bank accounts [62], thus they are increasingly becoming used to the idea of using their device for secure transactions. Since the population trusts mobile technology enough to use it to manage their bank accounts, logically they should be comfortable using it for voting.

2. *Owners of traditional feature phones or users of internet-enabled devices who do not pay for mobile internet are able to participate in the voting via SMS.*

This is essential as the total number of mobile subscriptions is much higher than the number of mobile broadband subscriptions. As of 2011 there are 6 billion mobile subscriptions [47], projected to increase to 6.5 billion by the end of 2012 [68]. Prices of SMS are falling in many countries such as China and US; the price of a text message is negligible in UK with most plans offering hundreds of free texts. The prices, however remain relatively higher in India [82]. As mobile penetration worldwide is higher than computer penetration (1.4 billion households owned a PC in 2011 [5]), SMS remains the most widely accessible form of voting. Voting via SMS is familiar and widely used in reality and entertainment shows such as Big Brother and the X-factor.

3. *The HandiVote mobile application is implemented as a web application optimised for mobile devices.*

This adds the benefit that the application can in practice be accessed via any internet-enabled device with a small cost in terms of usability due to, in practice, the interface being designed for smaller screens. Thus if users choose to, they could vote from their PCs and laptops.

### **1.3.4 Why we need a better, more transparent electronic voting?**

The recent experience from the US elections of electronic voting machines changing votes for Obama to votes for Romney [49] and the lack of votes paper trail have raised many controversies and have sparked the debate about transparent electronic voting. The HandiVote system supports verifiability of individual votes and allows for effortless audit and recounting of results.

## **1.4 Report Outline**

The rest of the report is structured as follows:

- Chapter 2 provides an overview of related work
- Chapter 3 discusses the design and implementation of the HandiVote system
- Chapter 4 describes two evaluations and two real life referenda conducted with HandiVote
- Chapter 5 concludes the report and discusses the implication of the evaluations in terms of future directions HandiVote could take

## Chapter 2

# Related Work and Background

This chapter will review academic work on the topic of electronic voting and will discuss several examples from countries that have trialled electronic voting. The HandiVote proposal will then be introduced.

### 2.1 Electronic Voting Requirements and Process

In order to ensure the public trust in the integrity of the voting process and in the validity of the result, any voting system should guarantee the following [20]:

1. **Anonymity** - it should be impossible to link voters to their votes;
2. **Confidentiality** - the ballot should be kept confidential and voters should not be able to prove how they voted;
3. **Integrity** - this requirement ensures that only valid votes are counted in the final result and that votes cannot be tampered with;
4. **Authentication** - only eligible voters are allowed to vote and their identity can be verified. Voters can only vote once;
5. **Verifiability** - *individual verifiability* refers to the notion that the voter is able to check that his/hers vote was recorded correctly; *Universal verifiability* means that the public can verify that the votes were counted correctly; It is worth mentioning, that if voters are able to verify their votes, they will inevitably be able to prove to others how they voted.

The voting process would typically involve the following stages [21]:

- Voter registration
- Placing the vote in an election or referendum
- Counting the votes
- Publishing the outcome

## 2.2 Related Academic Work

Electronic voting systems attempt to reduce the manual effort involved in one or more of the presented above voting stages, by fulfilling as many as possible of the electronic voting requirements. The following examples of automating the different voting stages can fit into more than one categories.

### Electronic Voter Registration

A proposal by Ibrahim [44] automates the registration stage by utilising public-private key infrastructure and RSA encryption. The voter sends their national insurance number to a central server via encrypted connection; the number is matched to a national registration database and if the voter is eligible, the system generates a RSA key-pair. The public key is stored in the voting database and the private key is sent back to the voter. The voter then votes by a complicated process of sending the ballot first to a validation service and then to a tallying service. Participation is limited to voters who own a computer, which is a significant drawback of this proposal. Fake names can be inserted in the national database by compromised insiders, thus allowing for additional illegitimate votes. Compromised insiders with access to the central server can record voter details and subsequently amend their votes. Finally, this proposal is unnecessarily complicated and might not be understood or accepted by the general public.

### Electronic Voting

Cetinkaya and Doganaksoy [14] propose a scheme where eligible voters receive pseudo-identity created using a blind signature. It guarantees voter anonymity as it cannot be traced back to the voter. Similarly to the HandiVote proposal, voters use their pseudo-identity and not their real identity when placing a vote. However, Cetinkaya and Doganaksoy's proposal uses a complicated cryptographic procedure to generate and distribute the pseudo-identities, which the general public might find difficult to grasp. The scheme also requires the use of a computer, which restricts access to voting.

A proposal somewhat similar to HandiVote is the mCESG scheme [73]. In this scheme the voters are provided with a polling card that contains voting credentials. Votes can be placed by sending an SMS with the voter number and candidate number printed on the polling card. Voters can confirm the receipt of their vote and that it was included in the final result correctly by visiting an official website, where a receipt number is displayed. The same receipt number can also be found on the polling card. The main difference with the HandiVote proposal lies in the distribution of the voting cards. With the mCESG scheme voters receive their polling cards via post, therefore if the authorities that issue the polling cards collude, the anonymity of the voters might be compromised. Furthermore, there is no mechanism to ensure that additional fake votes are not inserted in the system. Finally, as with any scheme relying on the post, there exists the possibility of polling cards getting lost. The mCESG scheme was evaluated in [74] with mixed responses - the security and the handling of personal information were causes of concern, while the mobility and convenience of the system were highly appreciated by voters.

### Electronic Counting

A proposal by Ryan and Schneider [70] automates the counting process and lets the voter verify the correct record of their vote. In their schema voters input their selection to an electronic machine inside the voting booth. The machine issues the voter with a receipt that is perforated in the middle, the one half of the receipt has to be discarded and the other half has to be scanned at a manned scanner to actually place the vote. Votes are counted

automatically. Voters can verify their vote was correctly recorded by checking an online bulletin board. A significant disadvantage of this system, is that it overcomplicates the voting process, as voting requires interaction first with one system to issue the receipt and then with another to scan the vote. If voters do not remove the one half of their receipt, the officials present at the voting scanner will be able to see their vote [21]. Voters can also prove to other people how they voted by giving them the receipt – verifiability eases vote selling. Finally, voters have to go to the voting location, thus this proposal does not make voting more accessible.

Another schema that allows vote verification is Chaum’s SureVote [16]. In this proposal the voting machine provides the voter with a receipt that consists of two layers. When placed on top of each other, the layers reveal the vote, while each layer by itself does not convey any information. The voter retains one of the layers as a receipt, while the other layer is shredded by poll staff. Similar proposal is VoteHere [64], where the voting machine displays a digit code corresponding to the selection. The digit code is generated uniquely for each voter, and retained as a paper receipt. The scheme depends on the voting machine correctly displaying the code. Both SureVote and VoteHere publish all the receipts after the election is over [30]. Voters can then verify that their votes entered the tally correctly. As the information displayed on the receipts is encrypted, voters could not prove the way they voted to other people. These schemes do not guarantee that fake votes have not been inserted. Voters also have to trust the system with correctly decrypting the receipts before counting. Both schemes are quite complex, and the SureVote schema requires sophisticated printers [51]. Researchers in [51] propose a scheme using the SureVote principle but instead of a 2 layer receipt, the voter is given a receipt with a barcode. The scheme, again, involves complicated encryption techniques.

## **Electronic Publishing**

Another mobile protocol is the M-SEAS proposal [12], which is essentially a Java based app that uses a complex encryption and blind signing process to transmit the vote. Apart from its complexity, the proposal relies on voters installing the app on their mobile phones.

A very similar scheme is proposed in [33] where voters are authenticated by their GSM operator and vote via an app installed on their mobile phone. The process relies on the assumption that the GSM operator verifies the identity of all subscribers.

Voting Scheme	Anonymity	Confidentiality	Integrity	Authentication	Verifiability
Ibrahim	vulnerable to compromised insider	vulnerable to compromised insider	vulnerable to compromised insider	yes	yes
Ryan & Schneider	compromised if half of ballot not removed	compromised if half of ballot not removed; can prove vote to others	yes	yes	yes
Cetinkaya	yes	yes	yes	yes	no
Chaum's SureVote	yes	yes	fake votes might be inserted	yes	voters have to trust votes decoded correctly
VoteHere	yes	yes	fake votes might be inserted	yes	voters have to trust votes decoded correctly
mCESG	compromised if authorities collude	compromised if authorities collude	fake votes might be inserted	questionable, since voting cards received by post	yes
M-SEAS	yes	yes	yes	yes	no
Feng	yes	yes	yes	questionable, performed by GSM operator	no

Table 2.1: Summary of related academic work

## 2.3 Country Experience with Electronic Voting

Nearly 20 countries currently use, or have trialled, electronic, mobile or internet voting.

Estonia uses web voting [59]. Estonian voters have ID cards with electronic chips that contain private keys. To vote, voters need to insert their ID card into a card reader connected to a computer. Their vote is first encrypted and digitally signed, before being placed online and sent to the electoral commission server. When it arrives at the server, the digital signature part of the vote, which identifies the voter, is placed in one list, and the encrypted vote is placed in another list and sent for counting. An electronic vote can be voided by voting at the polling station. This voting scheme is quite restrictive as voters require card readers and computers. Voters' computers might be infected with spyware that makes a record of their vote. An insider at the electoral server might be in a position to see the vote before it has been split, resulting in loss of anonymity. An insider could also insert fake votes into the server [21]. In the 2011 parliamentary elections Estonia allowed the use of mobile phones instead of card readers for voting [29]. However, voting with a mobile phone still had to be complemented by a computer with Internet connection - the voting process required voters to input their phone number at the official website and receive a message, before they could vote by SMS.

Switzerland uses a different approach to electronic voting [9]. Voters receive cards with stretch code. Voters can then vote online by providing this code and their place and date of birth. Until 2007 Swiss voters could also vote with SMS by sending the code from the card and their vote [38]. However this practice is now discontinued, as officials believe that there is not sufficient demand for it, due to most Swiss mobile phones being internet-enabled [38]. The information identifying the voter, and the vote itself, are kept in different files by the electoral commission. The main criticism of this mechanism (and the Estonian one) is that there remains the possibility

for an insider to obtain both files and thus match voters to their votes.

The use of direct-recording electronic (DRE) voting machines in US has given rise to much controversy. The DRE machines used in the 2000 US elections did not produce paper audit trail thus it was impossible to recount votes in the many cases when the correct recording and counting of votes by the DRE machines was challenged [25]. In the 2012 US election over 40 million voters were registered to vote on electronic voting machines with no paper audit trail [80]. In some cases the DRE machines have malfunctioned and lost all votes cast [50]. As the voters can not verify the record of their vote [30], security experts point out that unless the source code of the voting machine is examined, there is absolutely no guarantee as to what the system does [41]. However, the code is property of the manufacturer and not available for public scrutiny. A proposed change to the DRE machines involves the machine issuing a paper printout of the ballot to allow voters to verify the correct record of their votes [30]. This scheme is not without drawbacks, as it is possible that one voter could see another voter's paper printout.

The manufacturer of the DRE machines has complete control over counting of the votes [54]. This caused conflicts of interest in US around the 2004 presidential elections, as politicians were discovered to be owners or managers of voting machines' manufacturing companies or to have very close ties with these [42, 57]. The CEO of Diabold (manufacturer of voting machines) publicly promised Ohio's votes to President Bush [60]. This controversy gave rise to suspicions that the vote might have been rigged [48] as there were discrepancies between the exit polls and the results the Diabold machines were producing [58], with the machines consistently giving Bush higher votes than the exit polls [13]. Similar concerns surrounded the 2008 Primary Vote, as statistical analysis of the results showed systematically higher votes for Hilary Clinton from states that use the Diebold machines [15].

New controversies came to light with the 2012 Presidential Election in US, as many voting machines were reported (and even recorded on video) to change votes cast for Obama to votes for Romney [49]. The opposite was also reported. The fault was said to be a calibration issue, as some of the machines were apparently 10 years old [8]. Research confirms that Diebold machines are vulnerable to fraud and are error prone [42, 57]. The electronic voting machines used in Ohio were alleged to contain a vulnerability that would allow individuals to change the recorded votes [41]. Wide spread breakdowns of voting machines has also led to problems.

The design of voting system interfaces has significant impact on the ease of voting and the prevention of errors [30]. The complex interface of the DRE machines might have increased errors while voting, such as voting for the wrong candidate. Many voters also required assistance during voting, which decreases overall trust in the system, with 10% of voters reporting that they were not confident that their vote was correctly recorded [30].

A pilot of an internet voting system in the US was open for public testing and hacked within 36 hours by scientists [40] giving rise to the argument that internet voting should not be used in elections. This paper argues that while the HandiVote system similar to any software is far from immune to security attacks, the verifiability of the votes will allow any tampering to be discovered and prevent it from influencing the outcome of the voting.

Ireland spent 54 million euro on purchasing and storing Nedap voting machines, but the machines were disposed of in 2010 because of public distrust - the machines did not support any form of verification of the correct recording of votes [46, 75]. Similar concerns about the Nedap machines led to several electronic voting projects being cancelled in Germany and electronic voting that does not provide verifiability of votes and transparent counting being banned by the German Federal Constitutional Court in 2009 [23]. The Nedap voting machines were also banned in the Netherlands in 2007 after another controversy over election fraud facilitated by the lack of vote verifiability [56].

Norway introduced web based voting in the 2011 municipal elections [37]. The source code of the system was made available for public reviewing [7]. Voters cast their votes online and receive SMS confirmation, allow-



ing for verification of the correct record of the vote [7]. However, many accessibility problems were reported [66].

Finland used an electronic voting system in the 2008 municipal elections, but usability issues led to re-elections [32].

India, the largest democracy in the world, used Skytl Online Voting mechanism in the Gujarat state municipal elections in 2011 [6]. Voters register online and receive a password via SMS. The password is used for voting online. Voters receive receipts that could be used to verify that their vote entered the final result after the election is over. However voters can not verify that the particular way they voted was correctly recorded [17]. This is a significant problem as the source code of the system is proprietary and only open to limited expert reviews.

A good example of a voting process allowing for voter verification is the 1999 Indonesian elections, where voters could monitor online the tallying of the results [43].

In the 2002 UK local government elections 30 councils in England used SMS and internet voting [68]. Voters received sealed packages with voter PIN, password and the voting website. Then they had to access the internet and vote using these voter credentials. Voters could also vote by sending a SMS with the PIN, password and a candidate number they were supplied with beforehand. After placing the vote, voters would receive a confirmation text message. The availability of these alternative voting methods increased voter participation, with over 95% of voters being confident that their vote was securely recorded and sharing the opinion that telephone and internet voting was more convenient than polling station voting. However, a mechanism for voter verification was not provided.

The Scottish experience from the 2007 elections was notorious, as optical scanners used to electronically count the ballots resulted in 140 000 votes being discarded [45]. In 2014 Scottish residents will vote on a referendum on whether Scotland should remain part of the United Kingdom.

To conclude - there is clearly a widespread interest in more accessible mechanisms to encourage participation.

<b>Voting Scheme</b>	<b>Anonymity</b>	<b>Confidentiality</b>	<b>Integrity</b>	<b>Authentication</b>	<b>Verifiability</b>
Estonia	vulnerable to compromised insider threat	vulnerable to compromised insider threat	insider could insert fake votes	yes	no
Switzerland	vulnerable to compromised insider threat	vulnerable to compromised insider threat	vulnerable to compromised insider threat	yes	no
United States	yes, but not with paper printout	no, no paper trial	no, no paper trial	yes	no
Ireland	yes	yes	can not be verified	yes	no
Germany	yes	yes	can not be verified	yes	no
Norway	yes	yes	might be able to prove vote	yes	yes
India	yes	yes	yes	yes	no
UK	yes	yes	yes	yes	no

Table 2.2: Summary of country experience with electronic voting

## 2.4 Referenda on Economic Decisions

In 2010 the state of Oregon voted on a referendum to increase their income and corporate tax [26]. In 2012 the state of California followed with a referendum on income tax [53]. A referendum in 2013 will ask voters in Hampton Roads, Virginia, if they agree to a 1 % sales tax to raise funds for transportation projects [34]. In Switzerland members of the public collected 10 000 signatures and triggered a referendum on abolishing flat income tax, to be held in 2014 [10]. Between 1999 and 2012, the Swiss voted on referenda on various economic topics - the use of revenues from gambling and aviation fuel tax, adjustments to unemployment benefits, income and property taxes and VAT, spending on health care, removing the backing of the Swiss franc by gold [11].

All of these referenda reflect only one side of the issue. For example, a vote on tax has no corresponding vote on spending or borrowing. An opinion poll that balances the adjustments in tax and spending will be closer to reality, as budgets are always a trade-off between revenue and spending. Typically, the above referenda ask a Yes/No question. A referendum question with multiple options will capture more accurately the spectrum of voter preferences.

## 2.5 Background Review Implications

From the above review of related academic literature we can draw an additional set of desirable requirements for an electronic voting system:

- *in order to maintain trust, the voting process and the mechanism that the system is built on should be simple enough so that the general public can understand it*

The use of advanced cryptographic techniques that can be comprehended only by experts decreases the trust in the voting system [57].

- *voters should not have to blindly trust any system. A mechanism allowing the voters to verify that their votes entered the final result correctly should be available*

It is evident from the above countries' experiences and from the work of Evans and Smith [25, 30] that lack of verification of the correct recording of votes has led to public distrust, countless controversies, court cases and the banning of voting systems. If the same software is deployed across many machines and is discovered to be faulty, this could invalidate the voting [30]. In practice even a paper trail is not enough to foster trust in the voting mechanism. Lauer argues that voter verification is the only way to counteract electronic voting threats [55]. Therefore, in order to build trust, voters should be provided with the opportunity to verify first that their vote was recorded correctly and second that it entered the final result. It should also be possible to re-count the votes as a countermeasure to fraud allegations. The source code of the system should be open to public scrutiny.

- *voting should be accessible to as wide range of voters as possible, therefore voting should not be dependent on expensive equipment such as computers, scanners and card readers*

The HandiVote system allows for multichannel (computer, mobile device, SMS) voting, thus increasing convenience and accessibility. It also provides complete transparency of voting - voters are able (and possibly encouraged by political parties) to verify that their vote was correctly recorded and has entered the final result. With HandiVote there is no need for complicated cryptographic procedures, therefore there is also no need for devices with high processing power or additional expensive equipment.

## 2.6 HandiVote - Accessible, Verifiable, Anonymous Voting

In the HandiVote proposal as outlined in [20, 21, 22] the voting process goes through 3 stages:

1. **Registration:** Voters register for the referendum in person by presenting a proof of identity to the voting commission. A note is taken to make sure voters only register once, and only eligible voters are allowed to register. Voters then choose a random sealed envelope from a jar, containing a voter card with a SIM chip, a unique Voter ID number and a PIN. Only the voter knows which Voter ID belongs to him/her, thus the vote is anonymous. As the registration period closes, the list of Voter IDs on any leftover cards will be published and entered into the HandiVote system. This ensures that leftover cards cannot be used to insert fake votes.
2. **Voting:** Voters can place their vote either at the polls, by sending in a text message with their vote or by using a landline or a public phone. This makes voting widely accessible. Voter credentials (the Voter ID and PIN) have to be presented when voting and only correct combinations of Voter ID and PIN will be accepted as valid votes. In the case of voting by SMS the credentials will have to be included in the message. Any repeat vote that is different from the original vote will void the first and any subsequent votes. This reduces the incentive to steal voter cards.
3. **Verification:** At the end of the referendum votes are counted electronically and the result is published. Voter IDs, grouped by the option they voted for, are published. This allows voters to verify that their votes have been recorded correctly and have entered the final result. This arrangement also allows the public to verify that the votes were counted correctly. All unused Voter IDs are also published. This prevents the insertion of any fake votes. At this stage any other fraudulent activity will also be discovered.

The HandiVote mechanism should ideally be offered as an alternative to existing voting arrangements. As voters vote away from the polling places and can verify their votes, there exists the possibility for voters to sell their votes or be coerced into voting in a particular way. However, if voters suspect that they might be coerced, they can request during registration to only be able to vote at a polling booth. Finally, as referenda take place more often than elections and the issues under vote change, it is unlikely that any particular political or otherwise group will engage in buying votes.

The HandiVote proposal relies on the implementation of 2 systems. The first holds all valid card numbers and offers a validation web service. When presented with a card number and PIN, it responds with a binary indication of the validity of the credentials. The second system records and counts the votes.

## 2.7 Web Based Extension

This report will present the implementation of the HandiVote proposal as a web based mobile application. The registration stage remains unchanged. The voting stage is expanded. The HandiVote system implemented here supports three voting channels:

1. Voting via SMS with voting credentials and vote (similar to the original proposal)
2. Voting via mobile device browser
3. Voting via desktop browser

The advantage of the second and third channels is even more simplified voting - voters submit their credentials and votes via a graphical user interface. Compared to SMS, the GUI reduces the probability of error. In this implementation voters send SMS to a single number and not to multiple numbers as in the original proposal due to budgetary constraints.

The choice of the web interface implementation was motivated by the rising popularity of tablets and smartphones. However, the option to vote using SMS was included, as voting via the web interface requires a mobile device with internet connection, which despite the growing use of smartphones, is still too restrictive.

Finally, the verification stage remains unchanged - voters will be invited to view the results and verify their votes by accessing a web page, where all Voter IDs will be published, grouped by the option they were submitted for.

## 2.8 Conclusion

This chapter has argued the case for voting that is verifiable, anonymous and accessible. Moreover, voting should be flexible enough to support single and multiple (related) options. Details of HandiVote's extension to support these requirements were provided. The next chapter will present the design and implementation of the system.



Figure 2.1: Traditional direct democracy in Switzerland (Wikimedia).

# Chapter 3

## Design and Implementation

This chapter outlines the requirements, design and implementation of the HandiVote system.

### 3.1 Requirements

#### 3.1.1 Functional Requirements

The following actors were identified:

**Voter:** this actor uses the system to vote and see results of a referendum.

**Administrator:** this actor uses the system to set up a referendum and publish the results.

The following use cases describe the functionality of the system. Use case diagrams can be found in Appendix B. A voter is able to perform the following actions via a mobile or a desktop browser:

- Input Voter ID and PIN
- Vote by selecting an option from predefined list of options
- Voter is not allowed to abstain / spoil the ballot. While with a paper ballot the voter can recover from accidental error by requesting a new ballot, an electronic ballot does not provide this opportunity. To avoid accidental spoiling of ballots (the voter clicking on the wrong thing), this action will not be allowed
- View result after referendum is over
- Verify vote was recorded correctly after referendum is over
- View past referenda and past results

A voter is also able to vote by sending a SMS with their Voter ID, PIN and a number representing the option they wish to vote for.

An administrator is able to perform the following actions via a desktop web browser:

- Create referendum - this includes
  - Specify a title, start and end date for the referendum

- Specify up to 5 questions for each referendum
- Specify up to 5 options for each question
- Verify the referendum was correctly recorded, and if not, modify the referendum
- Delete referendum
- Start and stop referendum
- Calculate and publish results
- Access records of all previous, current and scheduled referenda
- Log in and log out
- Add new administrators to the system

Administrator can place a vote the same way as a voter.

Overall system requirements:

- Support for running 1 referendum at a time
- Support for referenda on budgetary and on non-budgetary issues
- Graphical user interface is provided
- An external web service is called to verify voter credentials; the external service returns 1 on valid credentials and 0 on invalid
- A stream of SMS messages from another external service will be received and processed
- PINs are not stored
- Only votes accompanied by valid credentials will be counted
- The original vote will be voided if subsequent different votes are received; In multidimensional referenda, where multiple choices for different issues will be submitted, any subsequent vote where the choice for one or more issues is different from the first vote will void the entire vote. This arrangement does not let voters recover from mistakes, as they cannot vote again - they can only void their vote. An alternative would be to let voters report the mistake and allow a re-vote. A statistical analysis in [20] concludes that both alternatives will result in correct overall outcome of the voting. However, not allowing voters to re-vote is more secure in terms of discouraging fraud.
- The original vote will not be voided if subsequent votes are identical
- Voters will not be notified whether the Voter ID - PIN combination they typed in was correct, as to discourage attempts to guess the credentials
- Any attempts to guess a PIN or break it using brute force techniques will be logged.
- Whenever an invalid combination of Voter ID - PIN is entered into the system, a log entry will be made for the Voter ID.
- Valid and invalid votes are stored in separate tables
- Records of repeat votes will be kept

- Support for up to 5 administrators; New administrators are added by existing administrators
- Support for scheduling of referenda for up to 5 years in the future
- The result of the referendum will be displayed both in numerical terms and visually using charts. Data visualisation is necessary as it makes comprehending information easier [79, 76].

### 3.1.2 Finding Feasible Referendum Outcome Subject to Budget Constraint

Voting on economic decisions on taxation and spending could result in outcomes that are inconsistent with balanced budget. For example voters might simultaneously vote for increase in spending and decrease in taxes, which might not be feasible (without increasing borrowing for example). The approach to finding a feasible referendum outcome that the HandiVote system implements is outlined in [19] and summarised below.

In order to find the feasible values that are closest to the values the voters actually voted for, the  $N$  issues under vote are represented as  $N$  axes in a space. Thus the feasible combination of changes is found as a point on an  $N$  dimensional plane (a hyper plane). This is achieved by first summing and averaging the percentage changes the voters voted for. These percentage changes can be represented as  $x_1 \dots x_n$ . The current revenue from taxation or the current spending for each of the issues can be represented as  $a_1 \dots a_n$ . Then the constraint that balances the budget for 5 issues under vote is the equation:

$$a_1x_1 + a_2x_2 + a_3x_3 + a_4x_4 + a_5x_5 = 0 \quad (3.1)$$

If we represent  $x_1 \dots x_5$  as the vector  $\mathbf{x} = (x_1 \dots x_5)$  and  $a_1 \dots a_5$  as the vector  $\mathbf{a} = (a_1 \dots a_5)$ , then the equation above can be expressed as the dot product  $\mathbf{a} \bullet \mathbf{x} = 0$ . (Dot product takes two vectors and returns a single value obtained by multiplying the corresponding entries and summing the product.) The vector  $a$  is normal to the hyper plane, i.e. it is perpendicular to it. This is because 2 vectors are perpendicular (or orthogonal) if their dot product is zero. The feasible combination of choices closest to the actual vote is the point  $r$ , which is the closest to the vector  $x$  point realisable on the hyper plane. The realisable point  $r$  can be found using this formula from analytic geometry:

$$\mathbf{r} = \mathbf{x} - \left( \frac{\mathbf{x} \bullet \mathbf{a}}{\mathbf{a} \bullet \mathbf{a}} \right) \bullet \mathbf{a} \quad (3.2)$$

Therefore, an algorithm will be programmed that applies this formula to the actual vote and produces the feasible combinations of expenditure and tax changes. The application of this algorithm on real UK data is demonstrated in Appendix F.

### 3.1.3 Non-functional Requirements

#### 1. Multiple access points and usability

- The application should be web based and accessible via a variety of mobile devices and mobile platforms
- The interface should be optimised for different screens sizes; The interface should be easy and intuitive to navigate and use by inexperienced users and as simple as possible; The system should provide consistent look and feel across all browsers and devices and the HandiVote logo should be present on each page of the interface.
- To make the referendum questions easily understandable, the system should support the wording of the tax and spending questions in terms of desired percentage changes in a particular tax or expenditure heading. Percentage changes are easier to comprehend than absolute values in billions of pounds [22].

## 2. Implementation technologies

- The system should be implemented using open source technologies as this allows for the software to be made publicly available free of charge and to be open to expert review. Independent inspection by experts is essential for creating trust in an electronic voting system [52].
- The system should be platform independent. It was decided against implementing the system as a native or a hybrid app for example for Android or iOS because this would significantly restrict the number of users that could potentially access the application. Another issue with native and hybrid apps is the need to download and install the app before use, which might deter some voters. An app would also make the process invisible, which would reduce trust. There is also the possibility that the mobile device is infected with malware.

## 3. Documentation

- User documentation and installation documentation should be provided and easy to use. These are provided in Appendix I and J.

## 4. Security

- As this system is a proof of concept, security is not a primary concern. Security threats are discussed in Section 3.3.

### 3.1.4 Survey on Mobile Phone Usage

One of the primary goals of this project is to conduct an evaluation of the HandiVote system. It was decided that this evaluation would be conducted among students and staff of the School of Computing Science at the University of Glasgow. It was important first to find out what types of devices our potential participants use. During the initial requirements gathering stage of the project a survey (Appendix C) was distributed among students and staff, asking participants about the kinds of phones they had and their mobile phone usage patterns. 73 participants filled in the survey. The results, presented in Appendix C, show that 96% of respondents have internet access on their phone and 80% of participants access the internet via their phone daily or weekly. The majority of the participants (54%) download apps few times monthly. In terms of types of phones, 60% of respondents had an Android OS device and 15% - an iOS device.

The survey supports the conclusion that a platform independent application is a better choice as it will be accessible to any device with internet access. The fact that the vast majority of respondents have internet access and use it regularly means that accessing the HandiVote system via their device will not present a challenge.

This survey cannot be considered representative of the wider population, as Computing Science students and staff will naturally be more technologically informed and in possession of the more advanced technology on the market. However, this survey is representative of some of the target users of HandiVote, as HandiVote is a system that could potentially mobilise younger voters by lowering the bar for participation.

## 3.2 Design

### 3.2.1 Architecture

The HandiVote application utilises a thin client / server architecture model, with clients sending requests over a network and the server processing the requests. The client / server architecture allows multiple users to access



the same functionality and data without the need to deploy the application locally. HandiVote utilises a n-tier architecture outlined in Figure 3.1.

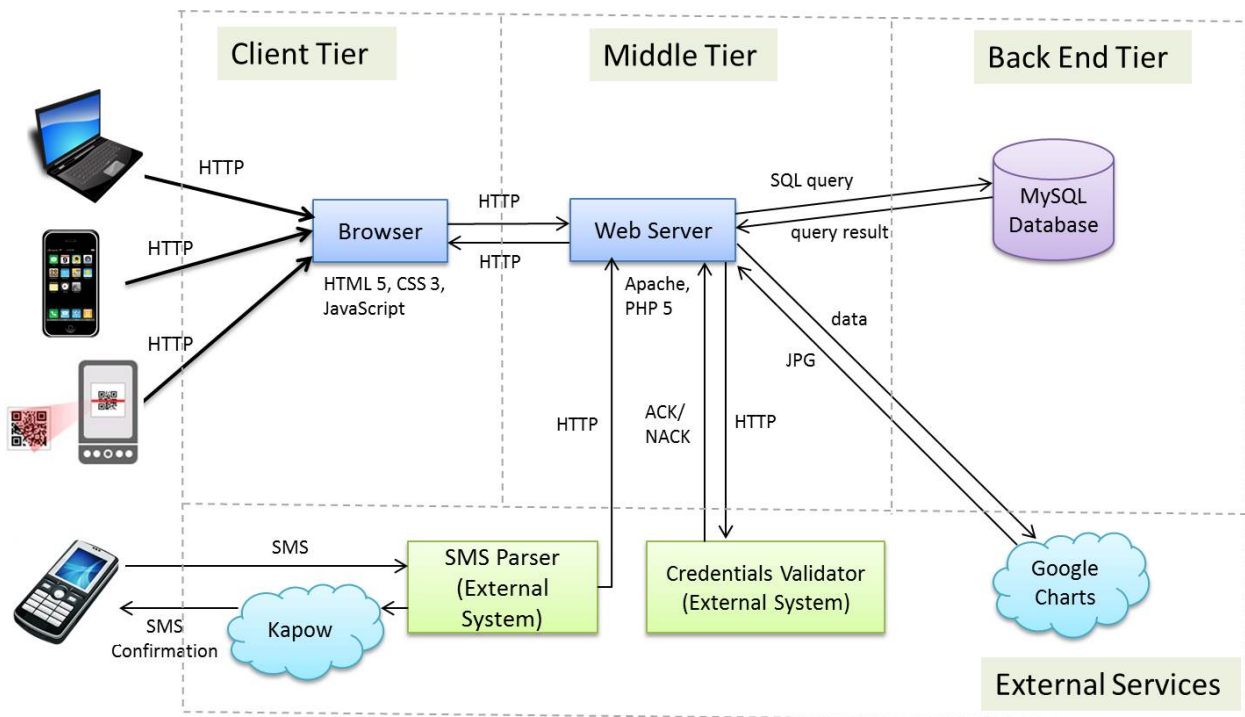


Figure 3.1: HandiVote Architecture.

The front end of the application is a computer or a mobile web browser interface. The server generates HTML that the browser displays to the user. Voters submit their votes either via the web interface in a browser (by visiting the link or by scanning a QR code) or by sending a SMS. SMS messages are parsed by an external service, a SMS Parser, which then passes the vote and credentials via HTTP request to the web server. An external service called Kapow is used to send an acknowledgement SMS to the voter. The browser also communicates with the server via HTTP requests. The server processes the requests and then sends HTTP request with the Voter ID and PIN to another external service, a Credentials Validator, which returns a message indicating whether the credentials are valid or not. This allows for good separation of concerns, as the HandiVote system does not have access to the valid combinations of credentials. The server then writes the system data to a MySQL database. The Google Charts API generates charts for visualisation of results.

### 3.2.2 Voting Process Design

The voting process is illustrated in Figure 3.2. Voters visit the web interface via a computer or a mobile browser. From the web interface they have the options to vote, if there is a running referendum, and to view the results of past referenda. Voters input their Voter ID and PIN to the web interface, and make one or more selections from dropdown lists. After receiving a vote, the browser displays a page with a confirmatory "Thank You" message. The result page links to pages with lists of Voter IDs, grouped by the referendum option they were submitted for. This facilitates user verification of votes.

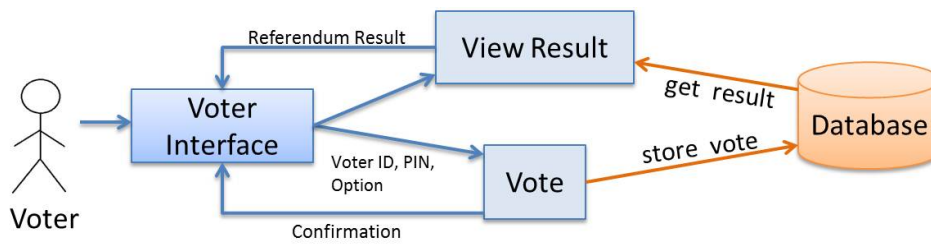


Figure 3.2: Voting Process

### 3.2.3 Administration Process Design

The administrator interaction with the system is displayed in Figure 3.3. The administrator accesses the administration functionality via a web browser. The administrator has to login with valid credentials. Once logged in, the administrator has the option to create a new referendum, view existing referenda, add another administrator or logout. If the administrator chooses to view an existing referendum, he or she is presented with further options for managing the referendum. These options depend on the status of the referendum and are displayed in Figure 3.4.

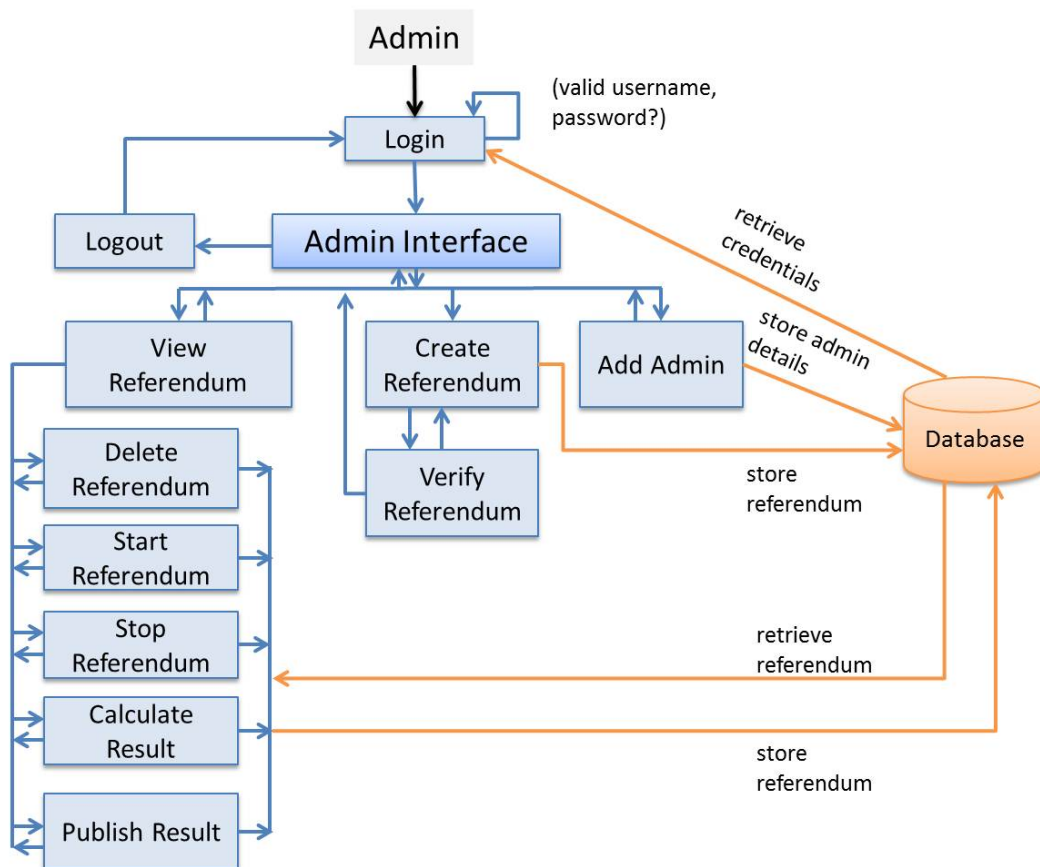


Figure 3.3: Administrator Interaction with the system

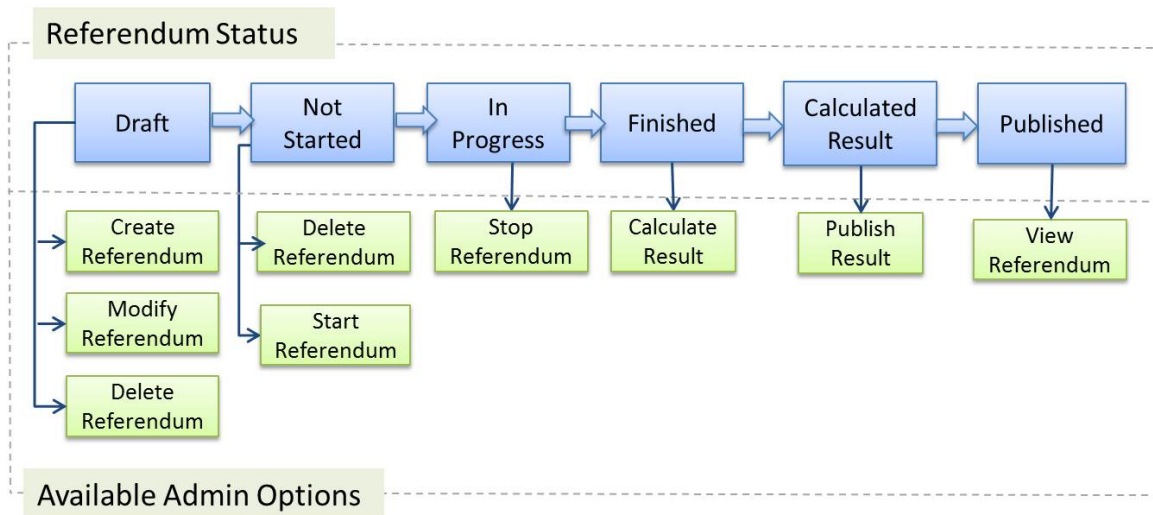


Figure 3.4: Available administration options depending on the status of the referendum

### 3.3 Security

Security is a top priority for any voting system as the integrity of the voting process has to be guaranteed at all times. If voters do not trust the security of the system, they will not use it to cast their votes. The following possible threats to the system were identified:

1. **Denial of service** -this is a network attack that attempts to make a service unavailable to its intended users. It is most commonly performed by overloading the server with requests, so that the server can no longer respond. If this were to happen during a referendum, the voters would no longer be able to vote through the attacked system. This type of attack can be mitigated by monitoring the incoming network traffic and configuring any firewalls and routers to block suspicious requests. This project did not implement technical protection against this attack as the server was on a university restricted access machine. However, the IP address of every voter was recorded and displayed back to them after voting, as to discourage them from attempting attacks.
2. **Man in the middle** - with this attack the data being transmitted over a network is intercepted and modified by an attacker. In the context of voting, this means that the vote and the Voter ID and PIN might be intercepted and changed, resulting in loss of voter anonymity and loss of integrity of the vote. The HTTPS protocol, which utilises encryption, can be used for the secure transmission of voter credentials and votes over the network as it protects against Man-in-the-middle attacks and eavesdropping. The HTTPS protocol was not implemented as it requires expensive certification.
3. **Social engineering and administrator interference** - these attacks might involve an attacker manipulating for example a systems administrator into disclosing information that gives the attacker access to the voting system. Alternatively, the administrator himself or herself could attempt to interfere with the system. A countermeasure is to establish security policies and train individuals with privileged access to behave in a secure way. Every change to the database can be logged, and deactivating logging can be protected by a separate password. Any use of this password can be tracked as well as any deactivation of the logging. Log files can be encrypted. Overall, there is no specific measure that fully protects from these attacks. HandiVote allows for full verification of votes thus any tampering with the system, such as insertion of fake votes or changing votes will be noticed.

4. **SQL injection** - with this attack SQL statements are included in the input to a web form with the goal of stealing information, modifying or destroying the database. The implementation of the HandiVote system includes protection against SQL injection - see Section 3.4.5.
5. **Malware** - voters' mobile devices or computers might be infected with malware such as viruses, Trojans or worms which might lead to loss of anonymity or tampering with the vote. However, the voter can always verify their vote, or if they suspect their device is not safe, they can send a SMS instead. Smartphones rely on more recent platforms, designed to prevent commonly known vulnerabilities. However, malware is becoming more common in smartphones, which can be the target of the same attacks as PC users [72].

The HandiVote system does not rely on voters to blindly trust the system. Instead it supports complete transparency by allowing vote verification, which means that any malicious activity will be discovered and can be investigated.

## 3.4 Implementation

The system was implemented in an agile manner, with requirements uncovered in stages through a series of paper and HTML prototypes. Development was iterative and incremental and new functionality was delivered weekly. This process was found to be most suitable given the exploratory nature of implementing a proof of concept.

### 3.4.1 Implementation Technologies

PHP was selected for the server side implementation primarily because PHP is cross platform, open source and efficient scripting language. HTML 5 (mark-up language for displaying web pages), CSS 3 (style sheet language) and JavaScript (client-side scripting language) are used for the client side implementation. HTML 5 and CSS 3 allow web interface optimisation for multiple screen sizes and devices and support web based apps that run on any device equipped with a browser. The Apache HTTP Server was selected for a web server, as it is high-performance, open-source, cross platform, and supports PHP [35]. Persistent data storage was implemented using the open source relational database management system MySQL. MySQL is a standard multi-user, cross platform system, which makes it suitable for web based applications but also free for non-profit use which made it the ideal choice in this setting. It allows the data to be accessed concurrently by multiple users, which is essential for an online voting system. MySQL provides API for PHP. MySQL can be accessed by a web browser from anywhere, which simplifies development [63]. PHP combined with MySQL are available cross platform, which means that the system can be developed on Windows and hosted on Unix [81]. Given this choice of technologies, the software bundle for Windows EasyPHP was utilised, as it enables development with PHP, MySQL and Apache on a personal machine.

Google Charts were used for visualisation of results as it is an open source, easy to use, flexible and powerful technology.

The SMS Gateway Kapow was used to send acknowledgement SMS messages to voters.

### 3.4.2 Database Design

The ER diagram is presented in Figure 3.5. The schema for the database is:

**REFERENDUM** (id, title, startDate, endDate, votes, status, revenue, revenue\_change, spending, spending\_change, degree)

**QUESTION** (id, refID, question, type, current\_spend, current\_tax, current\_tax\_pound, average, realisable)

**QUESTIONOPTION** (id, refID, qID, optionnum, option, value\_option, percent)

**VOTE** (id, barcode, questionID, optionID, void, ip, timestamp, refID, method)

**BAD VOTE** (id, refID, optID, barcode, ip, timestamp, type, method)

**RESULTS** (id, refID, qID, optionID, number\_votes, winner)

**ADMIN** (id, username, password, firstname, surname, email)

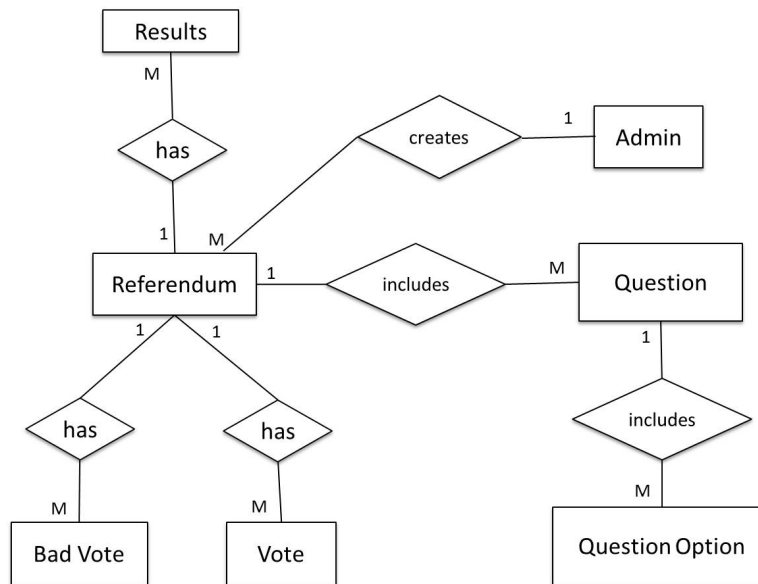


Figure 3.5: HandiVote Entity Relationship Diagram

### 3.4.3 Voter Interface

This section discusses the pages that the voter interacts with. Screenshots can be found in Appendix G.

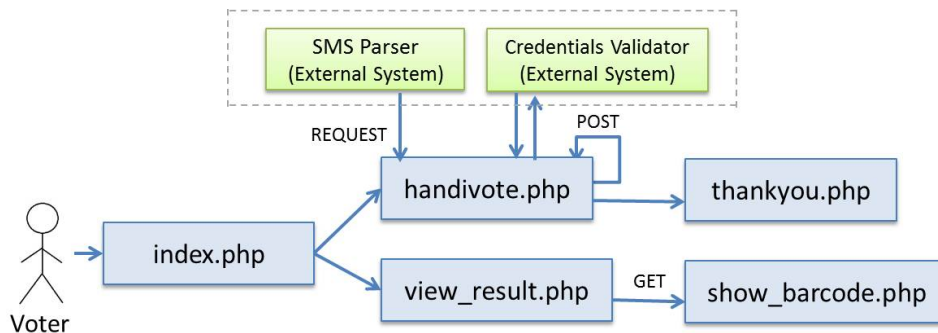


Figure 3.6: Pages voters interact with

**index.php** - home page of the application. From this page voters can access any running referendum as well as a list of all past referenda.

**handivote.php** - voters cast votes here.

**view\_result.php** - displays the result of the referendum.

**show\_barcode.php** - displays a list of Voter IDs of voters who voted for a particular option.

**thankyou.php** - displays a "Thank you" message after the voter has submitted their vote.

### 3.4.4 Administrator Interface

This section outlines the implementation of the administration interface. Screenshots of the files listed below can be found in Appendix G.

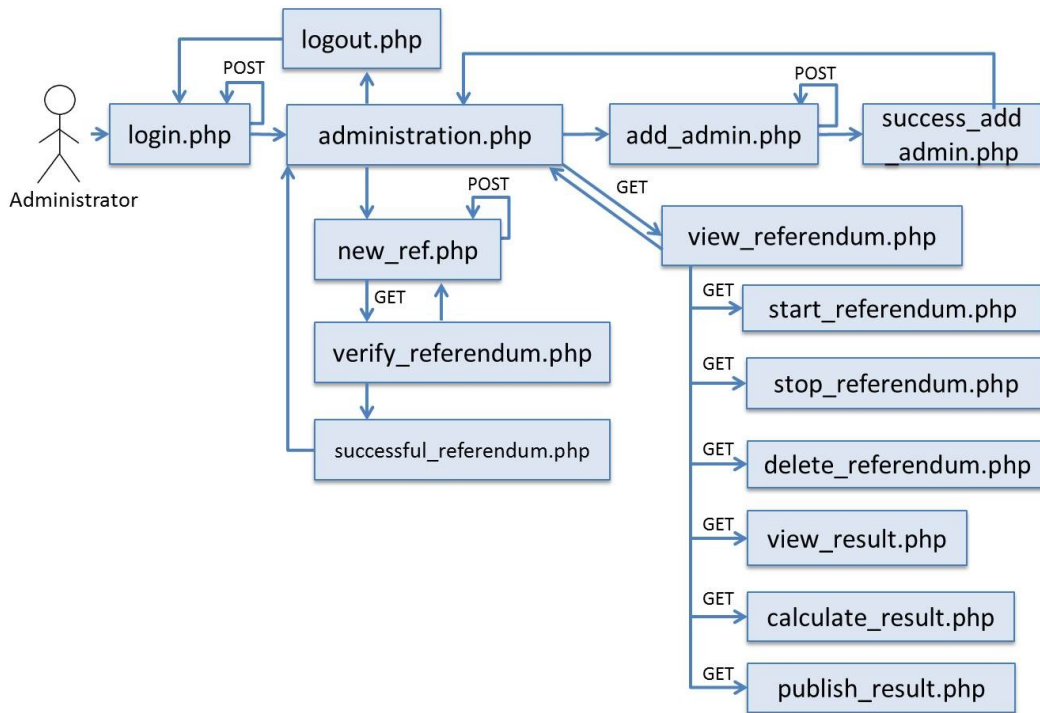


Figure 3.7: Pages that administrator interacts with

**administration.php** - main administration dashboard.

**new\_ref.php** - used to create a new referendum.

**verify\_referendum.php** - displays new referendum details so that the administrator can verify them.

**successful\_referendum.php** - displays a message confirming that the referendum was successfully created.

**add\_admin.php** - a form used to collect the details of a new administrator to be added to the system.

**success\_add\_admin.php** - displays a confirmation message that the new administrator was successfully added to the system.

**login.php** - administrator login page.

**logout.php** - destroys the current session.

**view\_referendum.php** - displays a referendum together with available options for that referendum depending on its status.

**start\_referendum.php** -starts the referendum.

**delete\_referendum.php** - deletes the referendum from the database.

**stop\_referendum.php** - stops a running referendum.

**calculate\_result.php** - calculates the result of a referendum and writes it to the database. For tax and spending questions the approach outlined in Section 3.1.2 is followed. This function is used to find the inner product of two vectors:

```
function inner_product($vector1, $vector2){
    $ip = 0;
    for ($i = 0; $i<count($vector1); $i++){
        $ip += $vector1[$i]*$vector2[$i];
    }
    return $ip;}

```

The inner products  $\mathbf{a} \bullet \mathbf{x}$  and  $\mathbf{a} \bullet \mathbf{a}$  are then calculated as follows (vector  $x$  is the array `$GLOBALS['percentage_changes']` and vector  $a$  is the array `$GLOBALS['current_income_spending']`):

```
$inner_productXA=inner_product($GLOBALS['percentage_changes'],
$GLOBALS['current_income_spending']);

$inner_productAA=inner_product($GLOBALS['current_income_spending'],
$GLOBALS['current_income_spending']);

```

The division of the two inner products is assigned to a variable

```
$scalar = $inner_productXA/$inner_productAA;
```

and the realisable point is found:

```
for ($i = 0; $i<count($GLOBALS['percentage_changes']); $i++){
    $realisable[$i]=$GLOBALS['percentage_changes'][$i]
    -$scalar*$GLOBALS['current_income_spending'][$i];
}

```

The interface allows for the level of current revenue/spending ( $a_n$ ) and the expected percentage change in revenue/spending in the next period ( $x_n$ ) to be entered (government borrowing can be entered under revenue). If that is the case, the product of the next period percentage change in revenue/spending and the current level of revenue/spending,  $a_n x_n$ , should also enter equations 3.1 and 3.2. However, when calculating the realisable point, all percentage changes are adjusted. Therefore the algorithm must ensure that **only** the choices made by the voters are adjusted while the term for next period percentage change in revenue/spending,  $x_n$ , remains the same. This is achieved as follows: after each iteration of the *forloop*, the resulting realisable values for the issues under vote are inserted in the the original vector  $x$ , while the term for the next period percentage change in revenue/spending,  $x_n$ , is replaced by its original value. The loop is repeated until the realisable values for the issues under vote become such that the term for percentage change in revenue/spending,  $x_n$ , converges to its original value. The algorithm can be summarised as follows:

1. Calculate realisable values
2. Has the percentage change in revenue/spending entered by the administrator converged to its original value? If yes, break out of the loop, if no continue with step 3.
3. Insert the realisable values for the issues under vote in their places in vector  $x$ ; percentage change in revenue/spending is replaced by its original value in vector  $x$ . Go back to 1.

The same procedure is applied if both a change in revenue and a change in spending for the next period are provided - the algorithm iterates until both values converge to their original values. The correctness of the feasible outcome can be verified by inserting the realisable values in place of vector  $x$  in equation 3.1 and making sure that the equation holds.

The degree of difference between the actual vote and the feasible outcome is calculated using the formula:

$$\sqrt{(x_1 - r_1)^2 + (x_2 - r_2)^2 + (x_3 - r_3)^2 + (x_4 - r_4)^2 + (x_5 - r_5)^2} \quad (3.3)$$

**publish\_result.php** - publishes a referendum.

### 3.4.5 Cross-Cutting Files

These files implement cross cutting concerns such as authentication and interface style formatting and are included by almost all other files.

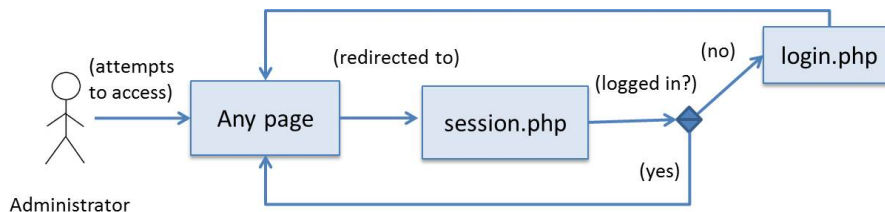


Figure 3.8: Authentication with session variables

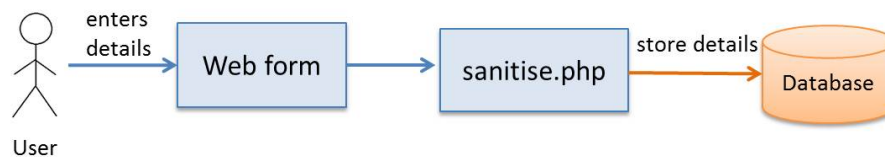


Figure 3.9: Sanitising input

**session.php** - this file starts a new session and checks whether the session variable "username" is set. If it is not set, the page redirects the user to login.php.

**sanitise.php** - this file contains a function that sanitises SQL statements to protect against SQL injection. The function is used to filter all web form input and remove whitespaces and escape characters:

```
function sanitize($data){
    $data = trim($data);
```



```
$data = stripslashes($data);  
$data = mysql_real_escape_string($data);  
return $data;}
```

After calling *sanitize()* the rest of the files use the PHP *sprint()* function to convert all input to string - this prevents any maliciously inserted SQL statements from being executed. The PHP function *mysql\_query()* is used to execute queries to the database as it allows only a single query to be executed, thus further increasing security.

**connection\_db.php** - configuration file for calls to external services and the database.

**script.js** - contains JavaScript scripts for user interaction with the interface and JavaScript alerts .

**css\_files.php** - contains links to several cascading style sheets.

### 3.4.6 Problems

The HandiVote implementation relies on 2 external services hosted on machines of the School of Computing Science. One of these services was down for a period of time in January 2013, which slowed down development, as it was not possible to test any changes.

The School machine hosting the HandiVote software went down shortly after the first evaluation in December 2012, thus making the software temporarily unavailable. This presented an issue, as voters temporarily could not see the results and verify their votes. The same problem occurred in February 2013, when publishing the results of the Common Room Poll was delayed by a few days due to the School machine being down.

## 3.5 Testing

A number of test cases were derived from the use cases of the system (Appendix H). Interactive testing against these test cases was performed by providing different sequences of inputs and carrying out typical user interactions with the system.

During development the Firefox built-in developer tools such as the error console and page source as well as the Firebug add on for Firefox were used to debug and test the application. The HTML pages were validated using the CSE HTML Validator Lite editor [1]. As the application had to be cross platform accessible, the compatibility with a variety of browsers was investigated. The system was tested across the most popular computer and mobile browsers: Firefox, Chrome, Microsoft Explorer, Opera, Safari, Android Browser, Dolphin, and Mobile Safari. Small difference in appearance were discovered, with the system appearing best in Chrome. Furthermore, the HTML 5 *required* tag and *number* input type were not supported by all browsers and corresponding changes had to be implemented on the server side. Mobile emulators such as MobiOne Studio [2] were used to test for the appearance and functionality of HandiVote across different smart phones and tablets.

The algorithm that calculates the feasible combinations of tax and spending changes within a balanced budget constraint was tested with real UK economic data (Appendix F).

## 3.6 Conclusion

This chapter presented the design and implementation of the HandiVote system. The evaluation of the system in the context of four different referenda will be presented in the next chapter.

## Chapter 4

# Evaluation

Voters should be given the opportunity to test any new electronic voting system by voting on an unrelated low importance topic, before participating in the actual voting that the system is deployed for [9]. With this in mind, two different evaluations were designed as part of this project. Two additional polls were requested by members of staff and by an external community and are also described here. The first evaluation was a simple 1 question referendum on a non-budgetary issue, while the second was a more complex multidimensional referendum on a budgetary issue. Finally, the third and fourth votings were 1 question opinion polls. We subsequently explored the usability of the HandiVote system both with a survey and with qualitative interviews.

### 4.1 Non-budgetary Evaluation

This evaluation involved students and staff from the School of Computing Science voting on a referendum with one question. The question concerned choosing a name for a robot, property of the School. Participants had to select one of 5 predefined options for the name.

#### 4.1.1 Aims

The first goal of this evaluation was to familiarise the voters with the system and the process. This evaluation was also designed to test the use of all channels for voting: staff members voted by SMS, one group of students voted via the web interface using a mobile device and another group of students used the web interface on a PC browser. The choice of a non-budgetary issue as a topic for the referendum allowed for a simple question and a large sample of participants. This would serve to reveal any issues with the software. A survey after the close of voting provided insight into the usability aspects of the system.

#### 4.1.2 Running the Evaluation

Before the evaluation students and staff from the School were asked to send in suggestions for a name of the robot. This was done to engage them with the topic. Several students were randomly selected to choose 5 of the suggested names. The HandiVote system requires the use of Voter ID and PIN as credentials. It was decided that staff are going to vote using their staff IDs (serving as a Voter ID) and a PIN provided by us. Cardboard cards with a PIN and instructions on how to vote via SMS were distributed to staff members. To avoid the logistics of distributing voter cards to students, it was decided to take advantage of the existing student cards - thus students

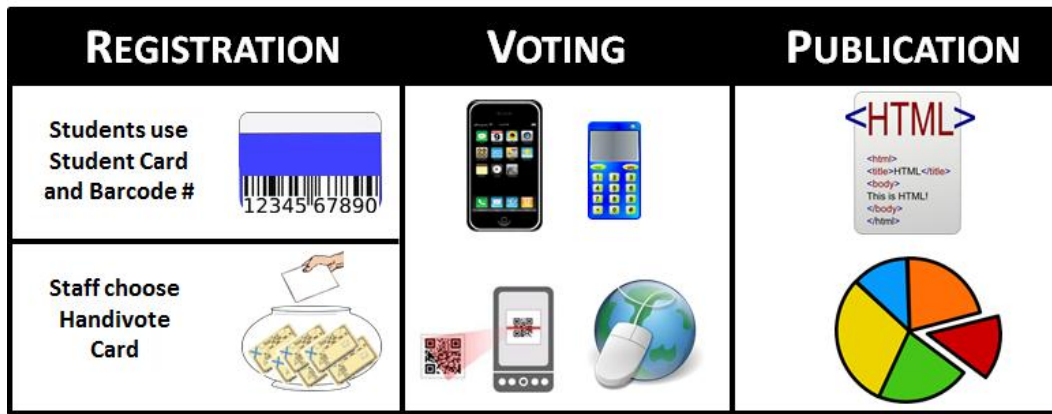


Figure 4.1: "Name the Robot" evaluation process

were asked to vote using their matric number (serving as a PIN) and their 14 digit student card barcode (serving as a Voter ID). Posters (Appendix D Fig D.1) were displayed across the School building and the student labs, informing students and staff about the campaign called "Name the Robot" and the suggestions for names. The poster featured a QR barcode [3] and a tinyurl [4] pointing to the HandiVote website, as well as instructions for voting via SMS. The web interface (Appendix D, Figure D.2) displayed the 5 options in different order for every voter, as to offset the effect of people voting more often for names on top of the list [31, 24]. Matric numbers were not recorded by the system to guarantee anonymity, and the barcodes were discarded after the referendum was over. A Smiley Face was added to the page confirming the receipt of the vote, as to create a positive association in voters' minds [71]. After the referendum was over the results were published (Appendix D, Figure D.3 ) and students and staff were invited to visit the HandiVote page to see the result, verify that their vote was recorded correctly and fill in a survey on their experience (Appendix D).

### 4.1.3 Results

83 participants took part in the referendum and 21 completed a survey on their voting experience. Out of the survey respondents, 28% voted via SMS, 33% voted via mobile device and 38% voted via computer. The survey focused on the following areas:

- **Ease of Use:** 76% of respondents found voting *very easy* or *easy*. 9% (2 respondents) found voting *hard*, however these 2 respondents were attempting to vote via the web interface with their Staff ID, while the web interface was set up to only accept student barcodes (staff were instructed to vote by sending SMS). 90% of voters found it *obvious* what they were supposed to do, while the same 9% from above did not find the task *obvious*. The GUI was characterised as *user-friendly*.
- **Verifiability:** 57% of respondents verified that their vote was recorded, and out of them 83% reported that their vote was recorded correctly, while 16% (2 respondents) could not find the record of their vote. These are the same 2 respondents from above, who most probably did not submit their votes correctly. Out of all respondents, 85% believed that the option to verify their vote was a *useful feature* of the voting system. They commented that verifying the vote increased trust in the system. However, some respondents lost their staff cards and could not verify their vote, while others pointed out that there should be a procedure to report and change any vote that was discovered as incorrectly recorded.
- **Voting on a national scale:** 65% of respondents stated that they would use the HandiVote system to vote in a national referendum such as whether Scotland should be an independent nation, while 25% would not use the system for a national referendum because of security concerns or belief that it is easy to make a

mistake and invalidate the vote. The rest of the respondents would use the HandiVote system on a national referendum depending on:

- how safe they perceive the system to be at the time of voting
- enough detail is made available about how the system functions internally and how private information is stored and used
- the availability of a process to report and change incorrectly recorded votes. Here the respondent also noted that this would actually open the system to abuse from people who changed their mind after seeing the referendum result

One respondent suggested that instead of voiding the original vote if a different vote is received, the system should just ignore any subsequent votes, or alternatively replace the earlier vote.

As a result of the evaluation it was discovered that:

- Students provided incorrect credentials to the system. For example they provided their matric number together with the first letter of their surname (while the system required the digits only) or mistyped their barcodes
- Some students were confused about which barcode they were supposed to provide, while others pointed out that barcodes are the default password for UNIX accounts
- Staff were attempting to vote via the web interface, which only accepted student barcodes
- There was demand for the opportunity to spoil the ballot (which was not provided)

As a result of these comments, several changes to the interface were made. The interface was adjusted to display more information on how to input the credentials and the input was validated more carefully to prevent voters from sending invalid credentials. A JavaScript alert was added to ask participants on submission to confirm that they had correctly typed in their credentials. A message was added to the interface that lets participants know that their matric numbers were not stored and their barcodes were being discarded after the referendum was over. To avoid the confusion for staff members, the web interface also accepted Staff IDs for the next evaluation.

## **4.2 Budgetary Evaluation**

The second evaluation asked School staff to vote on how they would spend any extra funding the School might receive at the end of the fiscal year. This scenario is realistic, which is desirable since it provides an incentive for staff to vote. The referendum consisted of 3 questions asking what proportion of the funding participants would spend on storage, processing power and equipment respectively. Each of the questions presented 4 options for allocation of spending 0%, 33%, 66%, 100%.

### **4.2.1 Aims**

The aims of this evaluation were:

- test the concept of voting on real budgetary issue
- test the usability of the software and the interface in the more complex setting of multiple questions with multiple options

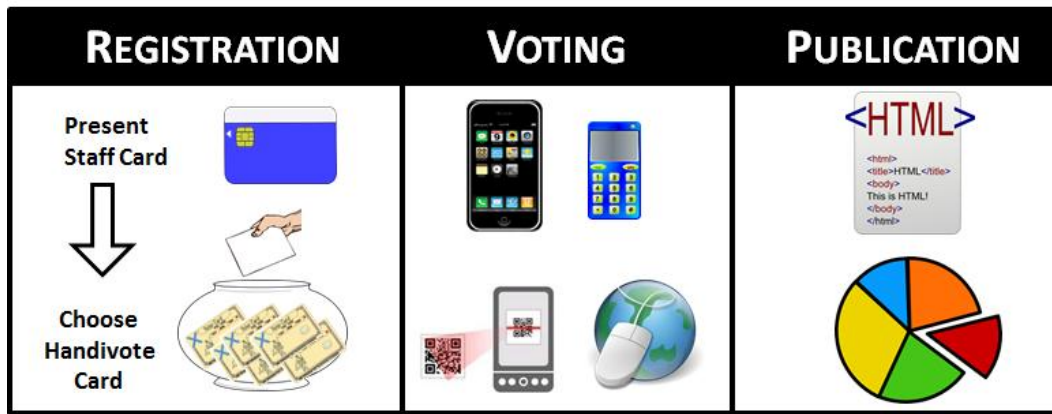


Figure 4.2: Budgetary evaluation process

- Find out the attitudes of voters to an outcome of the referendum that will not seem to reflect their votes exactly (as it is highly unlikely that the balanced budget solution will be exactly the same as any particular vote)

#### 4.2.2 Running the Evaluation

The second evaluation included adjustments based on the feedback from the first evaluation. Members of staff were provided with voting cards, each containing an 8 digit Card Number, a 4 digit PIN, a QR code and a link to the HandiVote website (Appendix E, Figure E.1). Voting via SMS, via browser and via scanning a QR code was supported. Voting via QR code was enhanced - when scanned, the QR code from the voting card would load the voting page in the device browser, with the unique Card Number and PIN from the card already pre-populated, thus avoiding the need to type in credentials and reducing the occurrences of errors. The reception of SMS votes was now acknowledged by a confirmation SMS. Voters were also given the opportunity to spoil their ballot by sending an empty SMS with valid credentials. Finally, the web interface now featured a screenshot of a voting card, with the voting credentials clearly highlighted so as to make it easier for the voters to understand how to vote. A screenshot of the interface is available in Appendix E, Figure E.2.

#### 4.2.3 Results

21 members of staff voted in the referendum, which represents over 50% turnout (nearly 40 cards were distributed). 14% voted via SMS, another 19% scanned the QR code on their voting cards and the rest (67%) accessed the web interface via the browser of a smartphone or a personal computer. The usability of the system appeared to have been improved as only one voter submitted an invalid vote, which was caused by him or her voting with 01234567 instead of their Card Number. 01234567 was used as an example vote displayed on the voting card, which might have caused the confusion.

Two qualitative interviews were conducted with members of staff on their voter experience (see Appendix E for transcripts). The aim was to establish the usability of the web interface, the voting card and the overall voting process. It was also interesting to find out whether the HandiVote system was perceived as appropriate for national level budgetary referenda. Overall, the voting system was regarded as easy and intuitive to use, and sufficient information and guidance was provided from both the web interface and the voting card. The availability of multiple voting channels as a means to lower participation barriers and the convenience of avoiding the trip to the voting booth were mentioned. However, voting via SMS was perceived as more challenging and potentially

error prone than voting via the web interface. The interviewees reported that they experienced no difficulties verifying their votes, as the lists of votes were sorted. They found the opportunity to verify their vote quite useful in increasing the transparency of the system. Both interviewees confirmed that they would like to vote on national budgetary decisions and that they would be comfortable to use the HandiVote system to place their votes. One of the interviewees, however, expressed reservations in his understanding of more advanced budgetary issues. The other interviewee insightfully pointed out that a referendum on taxation would not make sense without including a corresponding question on spending, and expressed his satisfaction with the ability of the HandiVote system to support multidimensional voting.

In terms of the voting process, the interviewees expressed concerns about what would happen if a card got lost or stolen. The interviewees appreciated that budgetary referenda leave scope for inconsistent votes and were comfortable with the concept of normalising the result subject to budget constraint. However, it was suggested that a link to a page explaining the applied mathematical procedures would be beneficial in establishing trust in the system. Publishing the source code of the systems for independent expert review was also recommended. Security issues were mentioned as a consideration, however the transparency of the system seemed to ease security concerns.

### **4.3 Staff Common Room Poll**

Staff from the School of Computing Science requested to use the HandiVote system to run a voting on how to refurbish a staff common room. As with the previous votings, voter cards were distributed (200 in total), and staff voted via SMS or via the web interface by submitting a 4 digit Card Number and a 4 digit PIN. The poll consisted of one question with a choice of 4 options.

55 members of staff voted in total, which represents a response rate of 27.5%. Out of them, 3 members of staff voted by SMS, and the rest (52) - via the web interface. Due to the shorter Card Number and PIN, no voters mistyped their credentials. However, two voters changed their votes repeatedly. A better awareness campaign is needed for any subsequent votings, so that voters understand that they are depriving themselves of a vote by re-voting.

### **4.4 North Kelvin Meadow Community Poll**

A fourth, medium-scale referendum was organised on request by a community group called North Kelvin Meadow Campaign. The Glasgow City Council was planning to build on a meadow and this group was opposing the move. The group wished to gauge community support for their campaign, and wanted to use HandiVote to achieve this in an anonymous and transparent way. The subsequent referendum asked residents of the surrounding area whether they agree or disagree with the meadow being build on. Approximately 3000 voting cards were distributed in sealed envelopes accompanied by a flier with instructions on how to vote. Voting was done via SMS as this voting channel was least likely to be the target of allegations of website hacking. For the purposes of future audits, a record of all mobile numbers that sent votes were kept (but without the accompanying vote). Over 200 votes were received by the time this report was submitted, and the referendum was scheduled to close on the 31st March.

### **4.5 Discussion**

The four referenda were very useful in that they helped uncover important issues, proved that the system is usable and that the software meets its requirements. It is very encouraging that School staff appreciated the usefulness

of the system and independently requested to use it. Even more promising is that the system was used for a medium-scale referendum among the wider public.

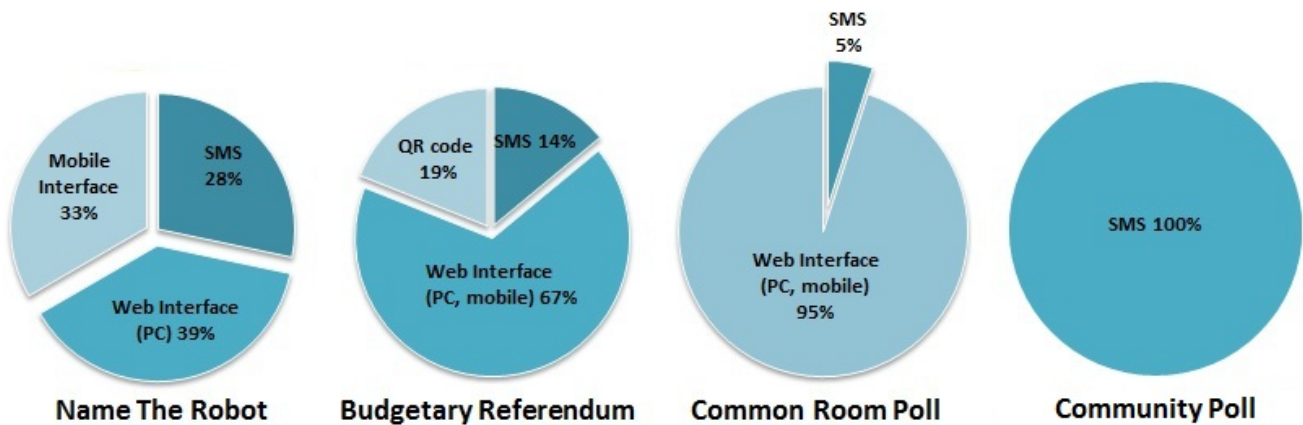


Figure 4.3: Comparison of voting channels

Based on the evaluations, it becomes clear that any large scale referendum has to be preceded by an information campaign, explaining the internal functioning of the system, its algorithms, the voting process and the mechanism for handling multiple votes. It was also confirmed that:

- Multichannel voting should be provided. An option to spoil the ballot should also be provided, as well as an explicit abstain option. By spoiling the ballot, voters could express their objection to the voting process, while by abstaining, voters could send the message that they do not feel strongly for either option. In terms of voting channels, voting via the web interface using a mobile device or a PC appeared to be most popular (Figure 4.3). Voters found voting by scanning a QR code quite convenient as well, however, this option is generally only available to users of smart phones, who have a barcode scanner app installed on their devices. The use of SMS was less popular and least usable.
- The length of the voting credentials (in digits) and the way they are presented on the voter card should be considered carefully. Unsurprisingly, it was discovered that the shorter the length of the voting credentials, the easier it becomes to vote.
- Receipt of SMS votes should be confirmed, as this puts voters at ease that they did not send their vote to the wrong number.
- The handling of multiple votes should be reconsidered. The current mechanism is designed to restrict attacks to the system, however in a "friendly" opinion poll the mechanism could be adjusted accordingly.

## 4.6 Conclusion

This chapter discussed the design, running and results of four evaluations of the HandiVote system. In the next final chapter we will draw overall conclusions about the project and will present some suggestions for future work.

## Chapter 5

# Discussion and Conclusion

### 5.1 Discussion

Successful electronic voting relies on more than the software - it requires careful process design and clear communication with the participating voters. This paper was concerned with both the implementation of the voting system HandiVote and its evaluation and application within real life context.

#### 5.1.1 Usability

The HandiVote system can be considered to have successfully met its requirements. Voters found the system friendly and intuitive, and the various voting channels increased convenience and lowered barriers to participation. Our second evaluation is an example of how a national budgetary referendum might be presented to voters. Encouragingly, voters felt comfortable even with the new voting paradigm of multidimensional voting. However, a real national referendum would require the intrinsic mathematical procedures to be made available and presented at an appropriate level to the wider public.

#### 5.1.2 Limitations

The HandiVote system is a prototype and a proof of concept, and, as such, lacks certain flexibility. The mathematical algorithm for normalising the votes requires carefully selected inputs to balance the budget. If these are not supplied in the appropriate fields of the interface, the outcome of the calculations might be meaningless or unexpected. The system does not provide much flexibility in setting the budgetary questions, as all tax and spending questions are expected to be worded around an increase or a decrease in values by a certain percent. Additional wording options would be desirable to allow for greater flexibility.

The system does not distinguish between votes coming via a desktop browser and votes coming from a mobile browser. Capturing the properties of the device used for voting would be very useful for future enhancements.



## 5.2 Future Work

As mentioned above the HandiVote system is a proof of concept that could be extended and improved in a number of ways.

### 5.2.1 Flexibility and Configurability

The system supports only 5 questions and 5 options per question. This could easily be extended to any number of questions and options.

The system could also be extended to provide more flexibility in setting the budgetary questions, by allowing other than *increase / decrease* types of questions.

Various mathematical procedures could be used to normalise the outcome of the voting. At least one more procedure could be implemented to allow the results to be compared, thus verifying the accuracy of the calculations.

The administrator could be provided with the opportunity to customise the visual presentation of the results page, by selecting the types of charts and graphs to be displayed and by adding additional text messages.

It would be better to tailor the voiding options to the context of the vote, so that the threat model is more closely matched.

### 5.2.2 Security

For the application to be used in larger scale referenda, the security concerns outlined in this report (Section 3.3) have to be considered and addressed. This is especially evident from the fact that the public opinion poll described in Section 4.4 was conducted only via SMS due to security concerns.

Admittedly, the HandiVote system is vulnerable to administrator interference. In particular, an administrator with access to the database is potentially the weakest link in the system. A process could be put in place to log every access to the database, so that any attempts to tamper with the votes is revealed. Such a process should be managed by an independent administrator and logs should be kept in a different data store.

### 5.2.3 Scalability and Availability

The application performed well during both evaluations, but neither evaluation posed a heavy load on the physical server the system was deployed on. As the server was a single point of failure, it is worth considering having a backup server to ensure that server failure will not affect the system availability and that the system can withstand higher traffic. The active-redundant architectural pattern can be applied to all key components.

### 5.2.4 Accessibility

One of the main rationales behind HandiVote is that it lowers the barriers to participation - voting is accessible from widely available pieces of technology such as desktops and phones. It would be beneficial, however, to extend the system to allow voters to customize elements of the interface [37] such as the font size (could be

useful for elderly voters), the colour scheme (useful for dyslexic or colour blind voters), and the language (e.g. in Scotland voters could have the option to select between Gaelic and English). The system could also be extended to ensure compatibility with assistive devices such as screen readers [37].

### **5.2.5 Larger Scale Evaluation**

Combined the first three referenda received 159 votes. At the time of submission of this report, additional 200 votes were received in the fourth referendum. The voter population for the first three referenda ranged from undergraduate and post-graduate Computing Science students to members of staff of the School of Computing Science. The fourth referendum took place among the wider public, but only made use of the SMS voting channel. Another, larger scale evaluation among the wider public that utilises all voting channels that HandiVote provides, would be beneficial, especially if target users were canvassed during and after the voting concluded to identify problems.

## **5.3 Personal Reflection**

As a Combined Honours student, I was exposed to programming to a lesser degree than my peers. However, my other subject, Business Economics, provided me with insight into economics related issues. I believe that this project has been an excellent learning opportunity, as it enabled me to expand my programming skills, exposing me to new technologies, and at the same time allowed me to apply my economics knowledge. During the project I gained a variety of new technical skills in the area software architecture, I improved my time management skills, and I had the opportunity to contribute to a conference paper. Overall I am very satisfied with the outcome of the project, the state of the software and the result of the evaluations.

## **5.4 Conclusion**

The HandiVote application has proven to be an easy to use tool that facilitates the democratic right to vote and offers the added benefit of handling multidimensional votes on budgetary referenda. The system can be deployed by anyone anywhere, since we plan to release the code via an open source forum. It facilitates running referenda at negligible cost and lowers the barriers to participation.

## **5.5 Acknowledgements**

I would like to thank my supervisors Karen and Paul for their guidance and support during the project. I would also like to thank Dr Lewis McKenzie for his input in formulating the budgetary scenario for the second evaluation. Finally, I would like to thank all students and staff who participated in the evaluations, surveys and interviews.

# Bibliography

- [1] CSE HTML Validator Lite. *Online:*<http://www.freehtmlvalidator.com/>. Accessed: 24/02/2013.
- [2] MobiOne Studio. *Online:*<http://www.genuitec.com/mobile/>. Accessed: 24/02/2013.
- [3] QR Code. *Online:*<http://qrcode.kaywa.com/>. Accessed: 24/02/2013.
- [4] TinyUrl.com. *Online:*<http://tinyurl.com/>. Accessed: 24/02/2013.
- [5] Tomi Ahonen. Digital Divide: Global Household Penetration Rates for Technology. <http://www.brightsideofnews.com/news/2011/1/26/digital-divide-global-household-penetration-rates-for-technology.aspx?pageid=1>, January 2011. Accessed: 24/02/2013.
- [6] Lakshmi Ajay. Business Standard: E-voting for IT land. *Online:*[http://www.business-standard.com/article/beyond-business/e-voting-for-it-land-111072300044\\_1.html](http://www.business-standard.com/article/beyond-business/e-voting-for-it-land-111072300044_1.html), July 2011. Accessed: 24/02/2013.
- [7] Elections BC. Discussion Paper: Internet Voting. *Online:*<http://www.elections.bc.ca/docs/Internet-Voting-Discussion-Paper.pdf>, August 2011. Accessed: 24/02/2013.
- [8] Benjamin B Bederson, Bongshin Lee, Robert M Sherman, Paul S Herrnson, and Richard G Niemi. Electronic voting system usability issues. In *Proceedings of the SIGCHI conference on Human factors in computing systems*, pages 145–152. ACM, 2003.
- [9] Nadja Braun, Swiss Federal Chancellery, and Bundeshaus West. E-Voting: Switzerland’s Projects and their Legal Framework—in a European Context. *Electronic Voting in Europe. Technology, Law, Politics and Society*, Bonn: *Gesellschaft für Informatik*, pages 43–52, 2004.
- [10] Giles Broom. Bloomberg: Swiss Bankers Battle Socialists to Keep Tax Breaks. *Online:*<http://www.bloomberg.com/news/2012-11-15/swiss-bankers-battle-socialists-to-keep-tax-breaks-for-jet-set.html>, Nov 2012. Accessed: 24/02/2013.
- [11] Schweizerische Bundeskanzlei. Chronologie Volksabstimmungen. *Online:*<http://www.admin.ch/>, Feb 2013. Accessed: 24/02/2013.
- [12] Stefano Campanelli, Alessandro Falleni, Fabio Martinelli, Marinella Petrocchi, and Anna Vaccarelli. Mobile implementation and formal verification of an e-voting system. In *Proceedings of the 2008 Third International Conference on Internet and Web Applications and Services*, pages 476–481. IEEE Computer Society, 2008.
- [13] David Card and Enrico Moretti. Does voting technology affect election outcomes? Touch-screen voting and the 2004 presidential election. *The Review of Economics and Statistics*, 89(4):660–673, 2007.
- [14] Orhan Cetinkaya and Ali Doganaksoy. Pseudo-voter identity (PVID) scheme for e-voting protocols. In *Availability, Reliability and Security, 2007. ARES 2007. The Second International Conference on*, pages 1190–1196. IEEE, 2007.

- [15] Chris Chatham. The Diebold Effect: Hillarys Votes Higher From Diebold Machines Even Controlling for Demographics (education, income, population, etc). *Online: <http://scienceblogs.com/developingintelligence/2008/01/15/the-diebold-effect-hillarys-vo/>*, Jan 2008. Accessed: 24/02/2013.
- [16] David Chaum. Secret-ballot receipts and transparent integrity. *Better and less-costly electronic voting and polling places*, 2002.
- [17] The city of Edmonton. Internet Voting FAQ. *Online: [http://www.edmonton.ca/city\\_government/municipal\\_elections/internet-voting-frequently-asked-questions.aspx38558](http://www.edmonton.ca/city_government/municipal_elections/internet-voting-frequently-asked-questions.aspx38558)*. Accessed: 24/02/2013.
- [18] Paul Cockshott, Karen Renaud, and Tsvetelina Valcheva. Democratising Budgetary Decisions via Handivote. In *Proceedings of the International CTS-UNAM-IFPO-WARP Seminar, Berlin*, pages 36 – 53, 8th and 9th February 2013.
- [19] PAUL COCKSHOTT, KAREN RENAUD, and TSVETELINA VALCHEVA. DEMOCRATISING BUDGETARY DECISIONS WITH HANDIVOTE. In *63rd Political Studies Association Annual International Conference. The Party's Over?*, pages 25 – 27. City Hall Cardiff, March 2013.
- [20] W.P. Cockshott and K. Renaud. A Proposal for Facilitating Anonymous and Auditable Electronic Plebcites.
- [21] W.P. Cockshott and K. Renaud. HandiVote: simple, anonymous, and auditable electronic voting. *Journal of information Technology and Politics*, 6(1):60 – 80.
- [22] W.P. Cockshott and K. Renaud. Information technology: Gateway to Direct Democracy.
- [23] Michael Collins. German High Court Outlaws Electronic Voting. *Online: <http://www.scoop.co.nz/stories/HL0910/S00187.htm>*, Oct 2009. Accessed: 24/02/2013.
- [24] Robert Darcy and Ian McAllister. Ballot position effects. *Electoral Studies*, 9(1):5–17, 1990.
- [25] David L Dill, Bruce Schneier, and Barbara Simons. Voting and technology: Who gets to count your vote. *Communications of the ACM*, 46(8):29–31, 2003.
- [26] The Economist. Oregon's tax referendums The pendulum swings back. *Online: <http://www.economist.com/node/15393573>*, Jan 2010. Accessed: 24/02/2013.
- [27] Education Scotland. Political Literacy: Referendums. <http://www.educationscotland.gov.uk/politicalliteracy/gettinginvolved/influencingparliament/referendums/index.asp>. Accessed: 24/02/2013.
- [28] Ericsson:. Ericsson Mobility Report. <http://www.ericsson.com/ericsson-mobility-report>, November 2012. Accessed: 24/02/2013.
- [29] Estonia.eu. Estonian e-voting system. *Online: <http://estonia.eu/about-estonia/economy-a-it/e-voting.html>*. Accessed: 24/02/2013.
- [30] David Evans and Nathanael Paul. Election security: Perception and reality. *Security & Privacy, IEEE*, 2(1):24–31, 2004.
- [31] A Felfernig, G Friedrich, B Gula, M Hitz, T Kruggel, G Leitner, R Melcher, D Riepan, S Strauss, E Teppan, et al. Persuasive recommendation: serial position effects in knowledge-based recommender systems. *Persuasive Technology*, pages 283–294, 2007.
- [32] Ed Felten. Finnish Court Orders Re-Vote After E-Voting Snafu. *Online: <https://freedom-to-tinker.com/blog/felten/finnish-court-orders-re-vote-after-e-voting-snafu/>*, Sept 2009. Accessed: 24/02/2013.

- [33] Yang Feng, Siaw-Lynn Ng, and S Schwiderski-Grosche. An electronic voting system using GSM mobile technology. *Royal Holloway, University of London Technical Report RHUL-MA-2006-5*, 2006.
- [34] Dave Forster. Legislator revives referendum on sales tax for roads. *Online: <http://hamptonroads.com/2012/12/legislator-revives-referendum-sales-tax-roads>*, Dec 2012. Accessed: 24/02/2013.
- [35] The Apache Software Foundation. *Online: <http://www.apache.org/>*. Accessed: 24/02/2013.
- [36] The Ford Foundation. FordFoundation 2010 Annual Report. *Online: <http://www.fordfoundation.org/about-us/2010-annual-report/engaging-citizens-to-strengthen-democracyelection-workers-confirm-voting-cards-note>* = Accessed: 24/02/2013.
- [37] Kristin Skeide Fuglerud and Till Halbach Røssvoll. An evaluation of web-based voting usability and accessibility. *Universal Access in the Information Society*, pages 1–15, 2011.
- [38] Jan Gerlach and Urs Gasser. Three case studies from Switzerland: E-voting. *Berkman Center Research Publication No, 3*, 2009.
- [39] The Guardian. Libyans vote in historic election. <http://www.educationscotland.gov.uk/politicalliteracy/gettinginvolved/influencingparliament/referendums/index.asp>, July 2012. Accessed: 24/02/2013.
- [40] Halderman. Hacking the D.C. Internet Voting Pilot. *Online: <https://freedom-tinker.com/blog/jhalderm/hacking-dc-internet-voting-pilot/>*, Oct 2010. Accessed: 24/02/2013.
- [41] Andrew Harris. BloombergBusinessweek: Ohio Candidate Sues to Block Electronic Voting Machines. *Online: <http://www.businessweek.com/news/2012-11-05/ohio-candidate-sues-to-block-electronic-voting-machines>*, Nov 2012. Accessed: 24/02/2013.
- [42] Bev Harris and D Allen. Black Box Voting: Vote Tampering in the 21st Century, 2003.
- [43] David Hill. Communication for a new democracy: Indonesia’s first online elections. *The Pacific Review*, 16(4):525–547, 2003.
- [44] Subariah Ibrahim, Maznah Kamat, Mazleena Salleh, and Shah Rizan Abdul Aziz. Secure E-voting with blind signature. In *Telecommunication Technology, 2003. NCTT 2003 Proceedings. 4th National Conference on*, pages 193–197. IEEE, 2003.
- [45] Digital Civil Rights in Europe. Failure of the Scottish e-counting system. *Online: <http://www.edri.org/edriagram/number5.9/scotland-e-counting>*, May 2007. Accessed: 24/02/2013.
- [46] IrishTimes.com. Controversial 55m e-voting machines to be scrapped. *Online: <http://www.irishtimes.com/newspaper/breaking/2012/0628/breaking50.html>*, June 2012. Accessed: 24/02/2013.
- [47] ITC. ITC: Facts and figures. <http://www.itu.int/ITU-D/ict/facts/2011/material/ICTFactsFigures2011.pdf>, 2011. Accessed: 24/02/2013.
- [48] Donald Kennedy. Election Science. *Science*, 306(5697):779–779, 2004.
- [49] Liz Klimas. More Electronic Voting Machines Changing Romney Votes to Obama. *Online: <http://www.theblaze.com/stories/2012/10/31/more-electronic-voting-machines-changing-romney-votes-to-obama-we-looked-into-it-and-heres-what-a-vendor-told-us/>*, Oct 2012. Accessed: 24/02/2013.
- [50] Liz Klimas. Why Are Some States Dumping Their Electronic Voting Machines and Going Back to Paper? *Online: <http://www.theblaze.com/stories/2012/11/01/why-are-some-states-dumping-their-electronic-voting-machines-and-going-back-to-paper/>*, Nov 2012. Accessed: 24/02/2013.

- [51] Marek Klonowski, Mirosław Kutylowski, Anna Lauks, and Filip Zagórski. A practical voting scheme with receipts. *Information Security*, pages 490–497, 2005.
- [52] Tadayoshi Kohno, Adam Stubblefield, Aviel D Rubin, and Dan S Wallach. Analysis of an electronic voting system. In *IEEE symposium on security and privacy*, pages 27–42. IEEE Computer Society, 2004.
- [53] KTVU and AP Wires. Cash-strapped California votes on tax increases. *Online: <http://www.ktvu.com/news/news/state-regional-govt-politics/cash-strapped-california-votes-tax-increases/nSySz/>*, Nov 2012. Accessed: 24/02/2013.
- [54] Lynn Landes. Elections in America—Assume Crooks Are In Control. *Online: <http://www.commondreams.org/views02/0916-04.htm>*, 2002. Accessed: 24/02/2013.
- [55] Thomas W Lauer. The risk of e-voting. *Electronic Journal of E-government*, 2(3):177–186, 2004.
- [56] Jan Libbenga. Dutch pull the plug on e-voting. *Online: [http://www.theregister.co.uk/2007/10/01/dutch\\_pull\\_plug\\_on\\_evoting/](http://www.theregister.co.uk/2007/10/01/dutch_pull_plug_on_evoting/)*, Oct 2007. Accessed: 24/02/2013.
- [57] Paula V Lippard. Ask me no questions, I'll tell you no lies;: Situational exigencies for interpersonal deception. *Western Journal of Communication (includes Communication Reports)*, 52(1):91–103, 1988.
- [58] Parenti M. and Wasserman B.H. The stolen election of 2004. 2007.
- [59] Epp Maaten. Towards remote e-voting: Estonian case. In *Electronic Voting in Europe—Technology, Law, Politics and Society: Workshop of the ESF TED Program Together With GI and OCG*. Bonn: Köllen Druck & Verlag GmbH, 2004.
- [60] Farhad Manjoo. Hacking democracy. *Online: [http://www.salon.com/tech/feature/2003/02/20/voting\\_machines/print.html](http://www.salon.com/tech/feature/2003/02/20/voting_machines/print.html)*, 2003. Accessed: 24/02/2013.
- [61] Mary Meeker. Internet Trends. <http://ondeviceresearch.com/blog>, May 2012. Accessed: 24/02/2013.
- [62] MobiThinking. Global mobile statistics. <http://mobithinking.com/mobile-marketing-tools/latest-mobile-stats/b>, December 2012. Accessed: 24/02/2013.
- [63] MySQL.com. Why MySQL? *Online: <http://www.mysql.com/why-mysql/>*. Accessed: 24/02/2013.
- [64] C Andrew Neff and Jim Adler. Verifiable e-voting: indisputable electronic elections at polling places. *VoteHere Inc*, 2003.
- [65] ITU News. Broadband Prices Are Falling. <https://itunews.itu.int/En/1686-Broadband-prices-are-falling.note.aspx>, 2011. Accessed: 24/02/2013.
- [66] Kommunal OG Regionaldepartementet. Evaluation of the e-voting trial in 2011. Accessibility for voters, trust, secrecy and election turnout. *Online: <http://www.regjeringen.no/nb/dep/krd/prosjekter/e-valg-2011-prosjektet/evaluering/evalueringen-av-e-valgforsoket-er-tilgje/summary-of-the-isf-report.html?id=685824>*. Accessed: 24/02/2013.
- [67] On Device Research. Mobile Market Research News. <http://www.kpcb.com/insights/2012-internet-trends>. Accessed: 24/02/2013.
- [68] Portio Research. Your Portio Research Free Mobile Factbook 2012. <http://www.portioresearch.com/en/free-mobile-factbook.aspx>, 2012. Accessed: 24/02/2013.
- [69] Robert Robertsson. Reuters: Voters in Iceland back new constitution, more resource control. *Online: <http://www.reuters.com/article/2012/10/21/us-iceland-referendum-idUSBRE89K09C20121021>*, Oct 2012. Accessed: 24/02/2013.

- [70] Peter Ryan and Steve Schneider. Prêt à voter with re-encryption mixes. *Computer Security–ESORICS 2006*, pages 313–326, 2006.
- [71] P Wesley Schultz, Jessica M Nolan, Robert B Cialdini, Noah J Goldstein, and Vidas Griskevicius. The constructive, destructive, and reconstructive power of social norms. *Psychological Science*, 18(5):429–434, 2007.
- [72] Australian Science. About malicious software in smartphones. *Online: <http://www.australianscience.com.au/technology/about-malicious-software-in-smartphones/>*, April 2012. Accessed: 24/02/2013.
- [73] Tim Storer and Ishbel Duncan. Practical remote electronic elections for the UK. In *Privacy, Security and Trust 2004 Proceedings of the Second Annual Conference on Privacy, Security and Trust*, pages 41–45. Citeseer, 2004.
- [74] Tim Storer, Linda Little, and Ishbel Duncan. An exploratory study of voter attitudes towards a pollsterless remote voting system. In *IaVoSS Workshop on Trustworthy Elections (WOTE 06) Pre-Proceedings*, pages 77–86. Citeseer, 2006.
- [75] Irish Times. E-voting machines to be disposed of. *Online: <http://www.irishtimes.com/newspaper/breaking/2010/1006/breaking26.html>*, Oct 2010. Accessed: 24/02/2013.
- [76] Edward R Tufte and E Weise Moeller. *Visual explanations: images and quantities, evidence and narrative*. Graphics Press Cheshire, CT, 1997.
- [77] UK Political Info. Voter Turnout by constituency, 2010 General Election. <http://www.ukpolitical.info/Turnout10.htm>. Accessed: 09/03/2013.
- [78] TSVETELINA VALCHEVA, KAREN RENAUD, and PAUL COCKSHOT. A Medium-Scale Trial of Handivote. Under Review.
- [79] MD Vernon. Presenting information in diagrams. *Educational Technology Research and Development*, 1(3):147–158, 1953.
- [80] Verified Voting. Internet Voting. *Online: <https://www.verifiedvoting.org/resources/internet-voting/>*. Accessed: 24/02/2013.
- [81] w3schools.com. PHP Introduction. *Online: [http://www.w3schools.com/php/php\\_intro.asp](http://www.w3schools.com/php/php_intro.asp)*. Accessed: 24/02/2013.
- [82] Karl Whitfield. Portio Research: Pricing Voice and SMS. <http://www.portioresearch.com/blog/2012/04/pricing-voice-and-sms.aspx>, April 2012. Accessed: 24/02/2013.
- [83] Yurong Yao and Lisa Murphy. Remote electronic voting systems: an exploration of voters’ perceptions and intention to use. *European Journal of Information Systems*, 16(2):106–120, 2007.
- [84] H.L. Zetterberg. *The Swedish public and nuclear energy: The referendum 1980*. United Nations University, 1980.

# Appendices



# Appendix A

## Acknowledgement of Sources

### A.1 Images

Smiley icon from <http://my.opera.com/HostDunkelheit/albums/showpic.dml?album=2402311&picture=32757181>

Handivote icon - courtesy of Keagan Renaud

Laptop icon from [http://vadonet.com/content/images/modern\\_portfolio/13.png](http://vadonet.com/content/images/modern_portfolio/13.png)

Phone icon from [http://www.sitesnstores-support.com.au/images/kb/kbaseicons/KBase%20icons/iphone\\_icon.jpg](http://www.sitesnstores-support.com.au/images/kb/kbaseicons/KBase%20icons/iphone_icon.jpg)

Scanning phone icon from <http://www.jayceooi.com/wp-content/uploads/2010/11/Barcode-Scanner.jpg>

Feature phone icon from <http://es.fordesigner.com/img/uploads/Image/cjbc/zcool/png20080526/1211813448.png>

Stick Figure from <http://www.themarysue.com/wp-content/uploads/2011/02/stick-figure.jpg>

### A.2 Code

Google Charts API was used for visualisation of results. Available from <https://developers.google.com/chart/>

Idea for code for sanitising input available from <http://www.bitrepository.com/sanitize-data-to-prevent-sql-injection-attacks.html>

CSS files available from <http://twitter.github.com/bootstrap/>

## Appendix B

# Use Case Diagrams

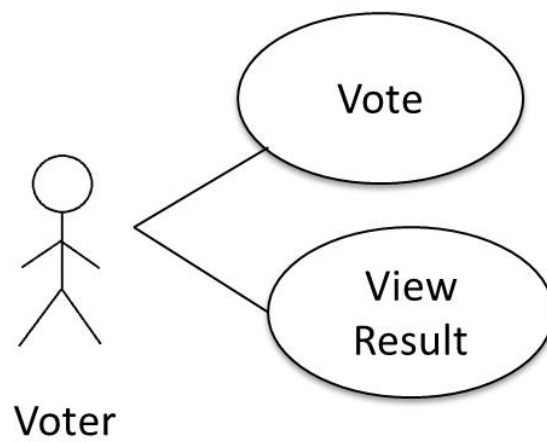


Figure B.1: Voter Use Case Diagram

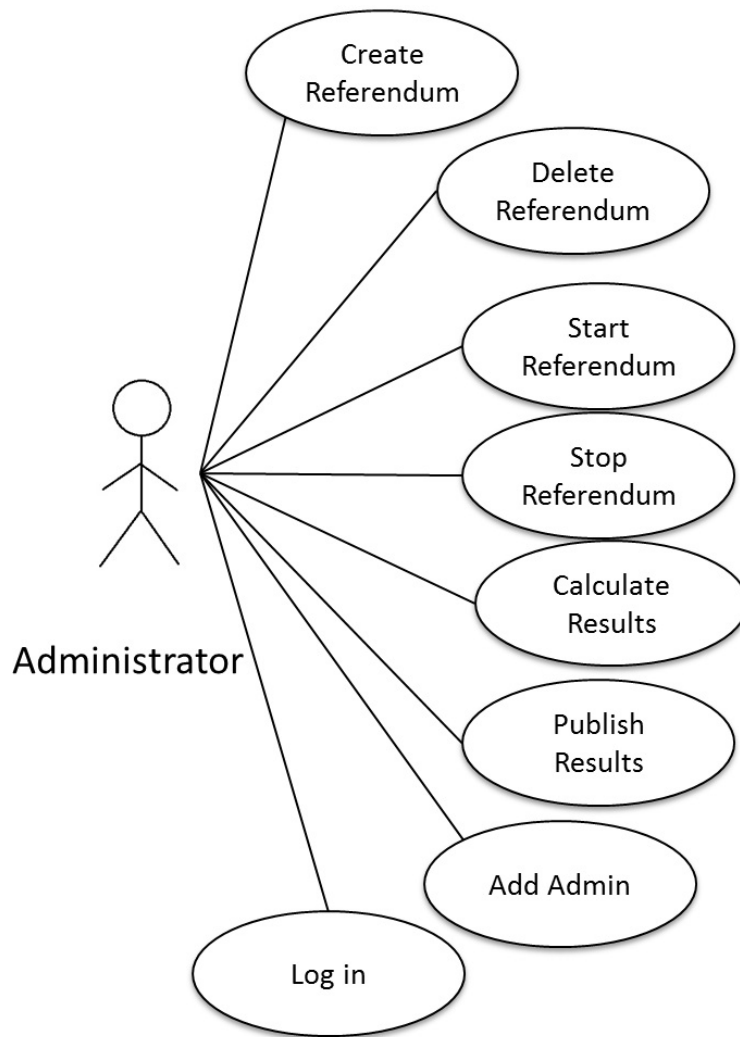
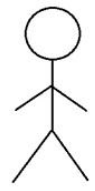
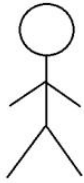


Figure B.2: Administrator Use Case Diagram



Voter



Administrator

Figure B.3: System Actors

## Appendix C

# Survey on Mobile Phones Usage

Questionnaire on Mobile Phones Use Participants were asked to answer the following questions:

1. Does your mobile phone have internet access?
  - yes
  - no
  - I dont have a phone
2. How often do you access the internet using your mobile phone?
  - every day
  - few times a week
  - few times a month
  - never
  - other (please give details)
3. How often do you download apps?
  - every day
  - few times a week
  - few times a month
  - never
  - other (please give details)
3. What type of mobile phone do you use?
  - iPhone
  - Android OS
  - Blackberry
  - Windows OS
  - Palm
  - Symbian
  - Other (please give details below)

Finally, participants were asked to suggest a name for the robot in the Computing Science department, if they wish to do so.

## Results

73 participants took part in the survey.

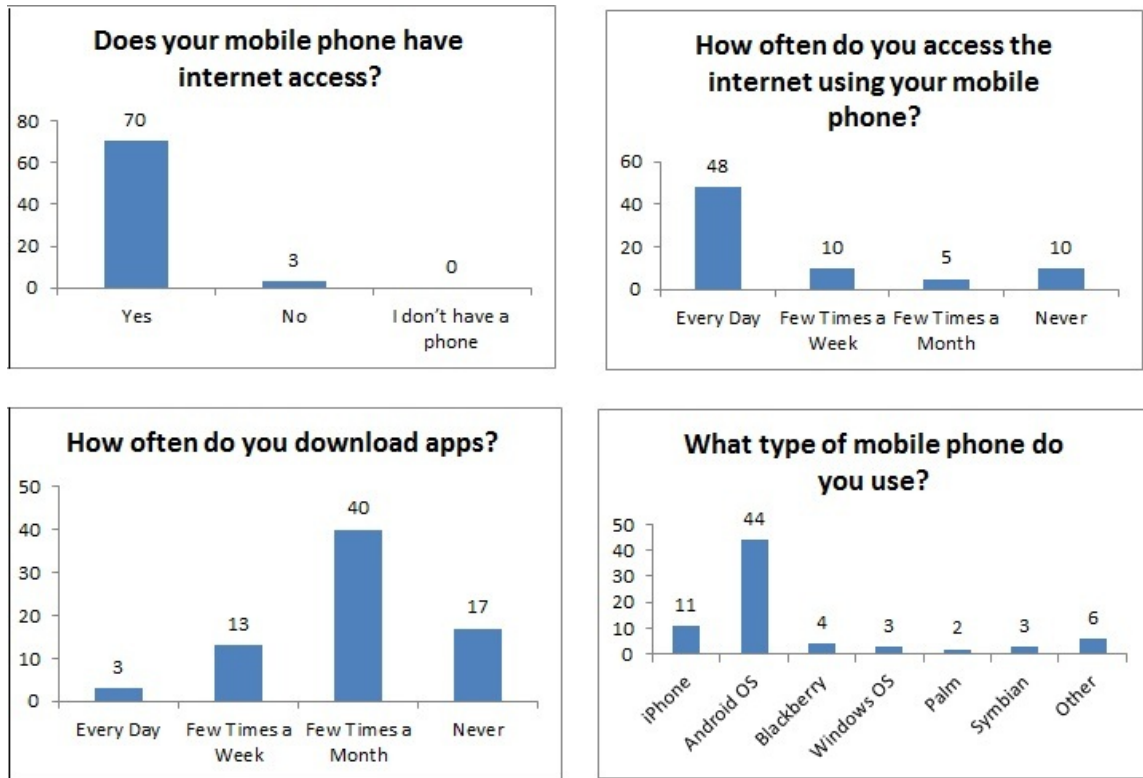


Figure C.1: Mobile Phone Usage Results



# Appendix D

## Evaluation 1



### Name this Robot!!!



(researchers at the Computing Science Department are going to teach it to fold things)



### 1. Pick a Name!

Choose between the 5 most popular names you've sent us:

- 1. Arcteryx (Greek God of Clothing)
- 2. Dexterous Blue
- 3. MARFF (Mechanical Automated Robot for Folding)
- 4. Segmentation Fold
- 5. The Smurf Bunny



### 2. Vote!

scan the barcode

or...



(tinyurl.com/handivote)

send SMS to **0745 006 8260** with:

» your barcode

0745 006 8260

Edit

» your matric number

28057448736567

0903784 6

» the number corresponding to your choice (between 1 and 5)



### Name The Robot

Question 1. What should we name the Robot?

Please select one..

- Arcteryx (Greek God of Clothing)
- Dexterous Blue
- The Smurf Bunny
- Segmentation Fold
- MARFF (Mechanical Automated Robot for Folding)

Barcode (the red code on your student card):

Please Note: Your anonymity is preserved. Matric Numbers will not be stored and Barcodes will be discarded after the referendum is over

Submit Vote

Figure D.2: "Name the Robot" Voting Page

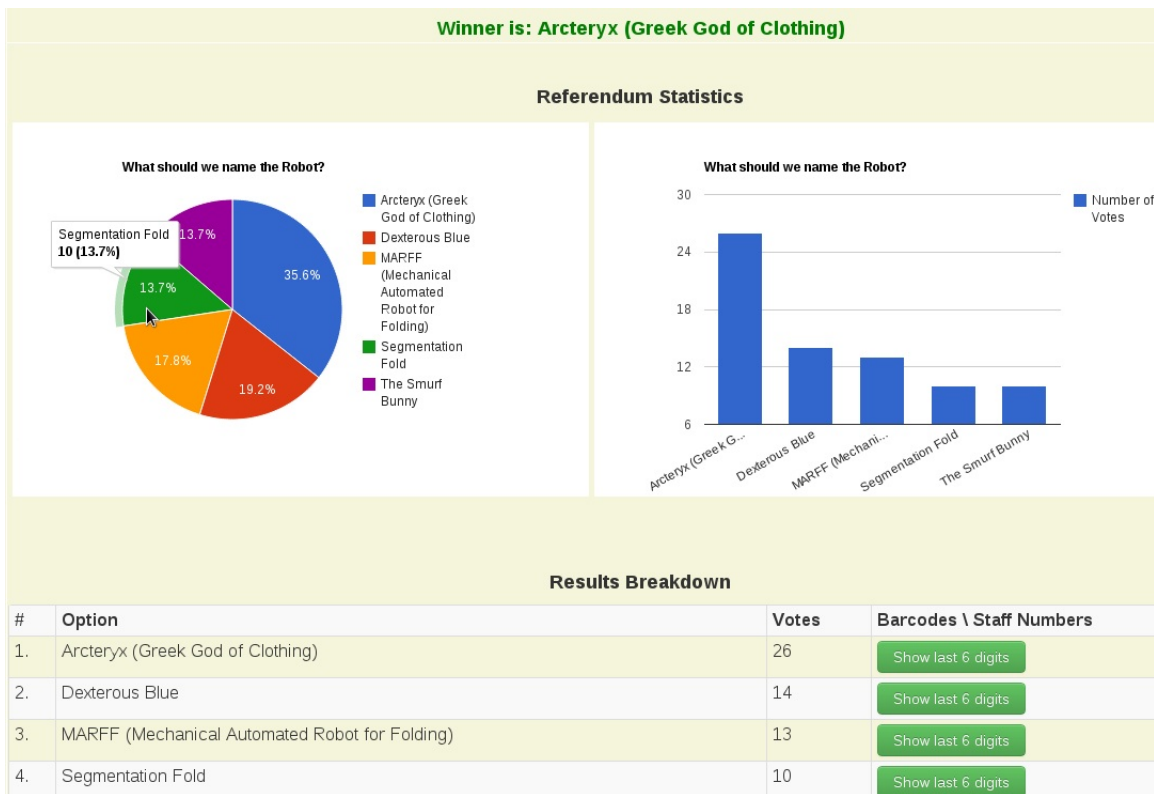


Figure D.3: "Name the Robot" Result Page

## D.1 Survey

The evaluation survey consisted of the following questions:

1. How did you vote?
  - I used my phone (or other mobile device) to open the referendum link / scan the barcode from a poster
  - I used my PC/ laptop to open the referendum link
  - I sent a SMS with my barcode and martric number / staff id
2. How easy/hard was it to vote?
  - Very Easy
  - Easy
  - OK
  - Hard
  - Very Hard
3. Was it obvious what you were supposed to do?
  - Yes
  - No
4. Did you go to the web page to try to verify your barcode/ staff id was recorded correctly once the result was published?
  - Yes
  - No
5. If you verified your barcode / staff id was your vote recorded correctly?
  - Yes
  - No
  - My vote was discarded
  - I could not find my barcode / staff id
  - Other (please specify)
6. Do you think that being able to verify that your vote was recorded correctly is a useful feature of a voting system?
  - Yes
  - No
  - I can't decide
  - Other (please specify)
7. Would you use this system to vote on a national referendum? For example on whether Scotland should be an independent nation?
  - Yes
  - No
  - I can't decide
  - It depends on:
8. Do you have any other comments on your voting experience?

## Results

21 Respondents completed the survey.

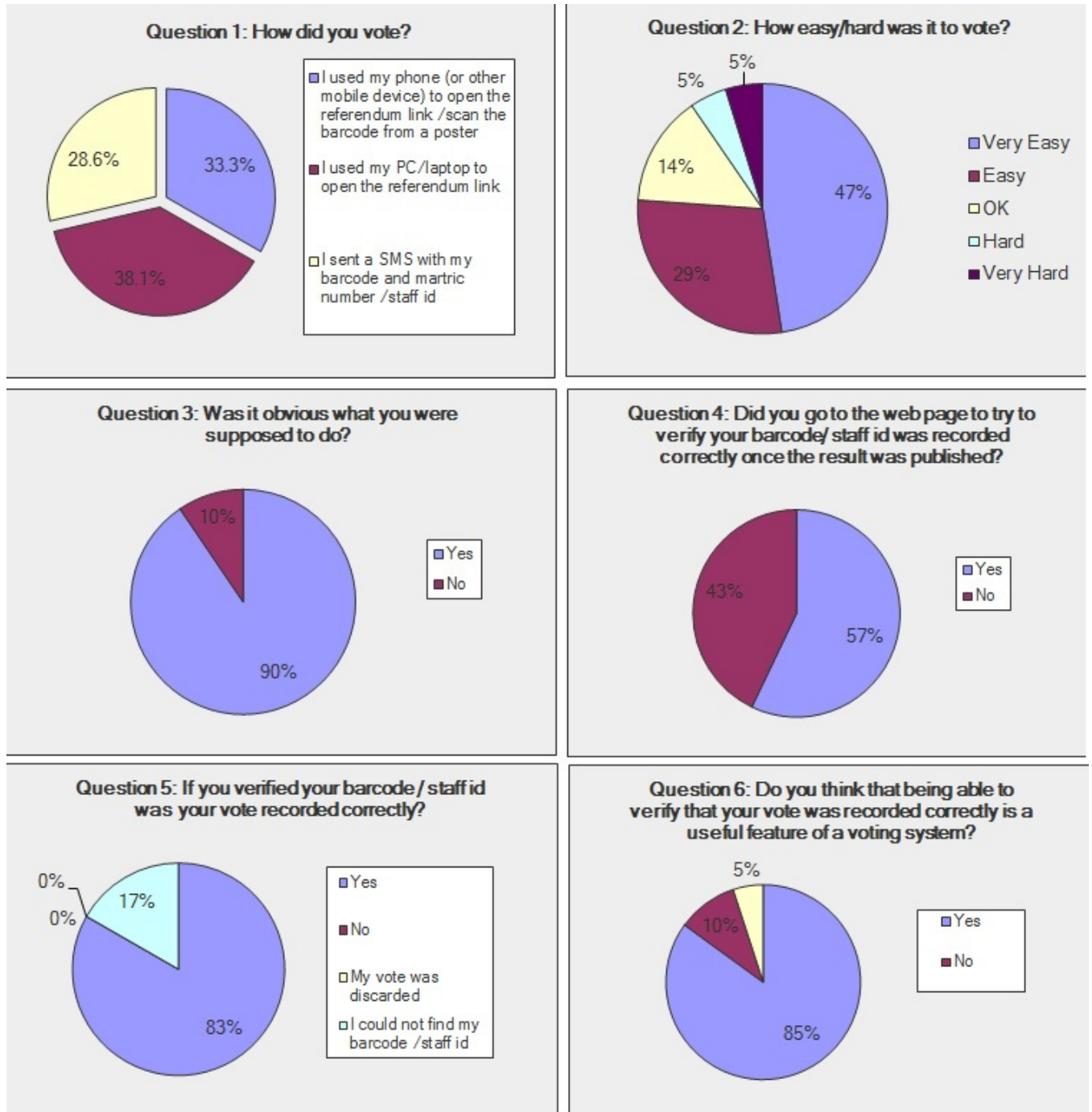


Figure D.4: Evaluation 1 Survey Results

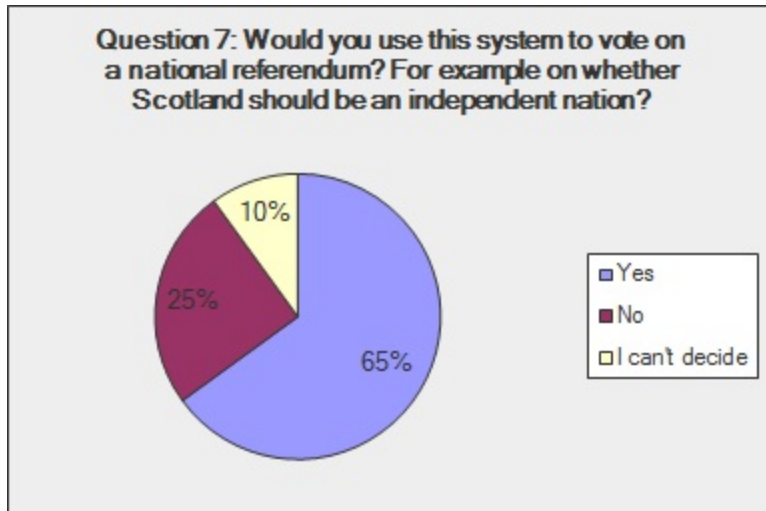


Figure D.5: Evaluation 1 Survey Results

# Appendix E

## Evaluation 2

Card Number: **5139 7813**  
PIN: **6739**  
Scan QR code:  
or SMS to:  
**0745 006 8260**  
or go to:  
[tinyurl.com/handivote](http://tinyurl.com/handivote)



How should spare funding in this years  
Equipment Budget be spent?

<b>STORAGE</b>	<b>0%</b>	<b>33%</b>	<b>66%</b>	<b>100%</b>
<b>PROCESSING POWER</b>	<b>0%</b>	<b>33%</b>	<b>66%</b>	<b>100%</b>
<b>PERSONAL KIT</b>	<b>0%</b>	<b>33%</b>	<b>66%</b>	<b>100%</b>

SMS EG. TO VOTE FOR 0% SPEND ON EVERYTHING:  
**0123 4567,0000** **0** **0** **0**  
Card Number                      PIN                      Storage                      Processing                      Personal Kit

Figure E.1: Voting Card

Please vote below on how any spare funding in this year's equipment budget should be allocated:

**Question 1.** What percentage of any extra funding should be spent on Additional Storage Capacity on the file servers?

Please select one... ▼

**Question 2.** What percentage of any extra funding should be spent on Additional Processing Power in the form of compute servers?

Please select one... ▼

**Question 3.** What percentage of any extra funding should be spent on more Personal Machines for staff?

Please select one... ▼

Please use the Voting Card you have received from us to vote. The Card Number and PIN can be found on the card (see picture). Please keep your Voting Card safe, as you will need the Card Number to verify your vote was recorded correctly after the referendum is over.



Card Number:   
PIN:

Submit Vote

Figure E.2: Budgetary Referendum Interface

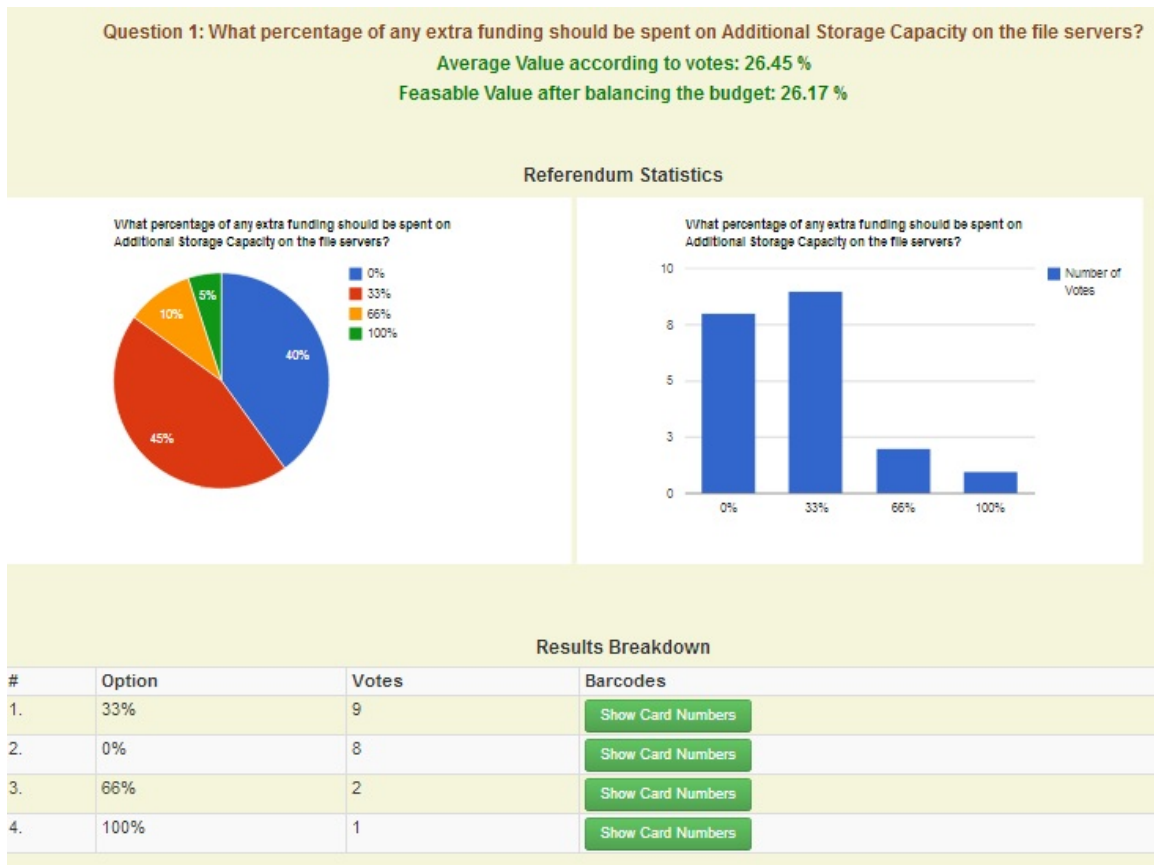


Figure E.3: Budgetary Referendum Results

## E.1 Transcript Interview 1

Q. How did you vote?

A. I typed in the tinyurl from my mac.

Q. Did the web interface provide sufficient information to help you understand what to do?

A. Yes, I made up mind just by looking at card, then voted.

Q. Were the instructions on the Voting Card sufficient to help you understand what to do?

A. Yes, the card helped me understand how to vote and what the options are.

Q. Overall, was it obvious what you were supposed to do?

A. Yes, I just typed something in and press a button.

Q. Did you verify your Card Number was recorded correctly once the result was published?

A. Yes.

Q. Did you have any difficulties finding your number? was looking for your number tedious?

A. No, because they were sorted, but if there were many numbers it would be more difficult, will have to do ctrl+f.

Q. If you verified your Card Number, was your vote recorded correctly?

A. Yes

Q. Do you think that being able to verify that your vote was recorded correctly is a useful feature of a voting system?

A. Yes, absolutely.

Q. Would you like to be given the opportunity to vote on referendums on national budgetary decisions, for example what the levels of government spending, taxation and borrowing should be?

A. Yes, possibly. I am a natural abstainer, big issues like that are important, more informed people should decide. I don't think I have enough information to be able to decide on issues like that.

Q. Would you use the HandiVote system to vote on a national budgetary referendum, if there was one?

A. Yes

Q. What did you think of the whole process - distributing card, voting, verifying vote? - too many steps, too complicated, is it realistic to use this process

A. I was worried that someone else might take my card and vote on my behalf, then I wouldn't be able to vote. Then I thought I lost my card.

Q. Did the concept of normalising the result become clear to you?

A. Yes, it was a bit suspicious because of the "we had to adjust figures" statement. It would be nice to have a link to calculations. The source code is not appropriate for the general public. Just high level calculations are useful to establish trust.

Q. Do you have any suggestions for improvement / anything you were not happy about?

A. No, everything seemed ok.

Q. Do you have any other comments on your voting experience?

A. I didn't know anyone who uses QR codes. I was tempted to send a SMS but didn't, because I wasn't sure what was going to happen when I text the number. I was not sure what number had to be included in the text. I did not quite understand how SMS voting works, it was not clear to me, I did not understand that that was the message body on the card. I was also worried about spaces, didn't know whether I should input the spaces in the interface and SMS.

## **E.2 Transcript Interview 2**

Q. How did you vote?

A. I used my PC to open the referendum link, I typed in the tinyurl.

Q. Did the web interface provide sufficient information to help you understand what to do?

A. Yes, it was easy to use, I barely needed the instructions the on card.

Q. Were the instructions on the Voting Card sufficient to help you understand what to do?

A. Yes, it was fine, if I wasn't in front of pc, I would have voted with phone

Q. Overall, was it obvious what you were supposed to do?

A. Yes

Q. Did you verify your Card Number was recorded correctly once the result was published?



A. Yes

Q. Did you have any difficulties finding your number? was looking for your number tedious?

A. No, there weren't that many numbers, it was easy.

Q. If you verified your Card Number, was your vote recorded correctly?

A. Yes, knowing that the vote was recorded was useful; if it was vote on something critical it would of been useful.

Q. Do you think that being able to verify that your vote was recorded correctly is a useful feature of a voting system?

A. Yes

Q. Would you like to be given the opportunity to vote on referendums on national budgetary decisions, for example what the levels of government spending, taxaton and borrowing should be?

A. Yes, I would love to. All these things are coupled, no point voting on income tax without voting on spending, otherwise wouldn't make sense. In this voting you could choose pattern that was inconsistent, and with any system that has multiple constraints, you are allowed to vote independently. I would like to be able to vote on income tax, spending but in a consistent manner - on all of them.

Q. Would you use the HandiVote system to vote on a national budgetary referendum, if there was one?

A. Yes

Q. Was the interface ok for multiple questions?

A. Yes, easy to use, interface was fine. Security is an issue, but in UK postal voting is not very secure anyway. I am concerned not so much about people discovering my vote - I am more worried about making sure that system is not open to abuse - eg like postal voting is open to abuse. You need to make sure system can not be abused; need to give a prove that system can not be abused; I don't think handivote looks like it could be abused.

Q. What did you think of the whole process - distributing card, voting, verifying vote? - too many steps, too complicated, is it realistic to use this process?

A. Not too complicated, not too many steps.

Q. Did the concept of normalising the result become clear to you?

A. Yes, useful for transparency would be to have a link to calculations, what would happen with inconsistent votes.

Q. Do yo have any suggestions for improvement / anything you were not happy about?

A. How are you going to reassure people that it is not open to abuse? what happens with inconsistent votes? Voting is simple, like that I didn't have to use phone, instead I could use what was convenient.

Q. Do you have any other comments on your voting experience?

A. Nice to have a system like this for major votes, will make life easier not to go to polling stations, also to vote more frequently. Nice piece of work. Virtually every body has a phone, can text. Good to publish code, paranoid people would check it up, transparent, fact that is available makes it more trustworthy, good if can be verified by independent experts.

## Appendix F

### Example Calculations with UK data

Let us take a hypothetical example approximately based on the 2011 UK Budget in order to demonstrate the application of the algorithm. We can construct a referendum based on the following 2011 UK Budget figures:

<b>Budget Heading: Revenue</b>	Amount for 2011
VAT = 20%	Approximately $£86 \times 10^9$
Income Tax, assumed to be flat at 30% for all income groups for simplicity	Approximately $£153 \times 10^9$
<b>Budget Heading: Spending</b>	
Pensions	Approximately $£120 \times 10^9$
Health Care	Approximately $£121 \times 10^9$
<b>Budget Heading: Borrowing</b>	
Government Borrowing	$£2 \times 10^9$ (This figure is not real, rather it was chosen to balance the budget in this example)

Now let us assume that the referendum in this example consists of 4 questions, each asking for adjusting (increasing, decreasing or keeping the same) the values of VAT, Income Tax, Spending for Pensions, and Spending for Health Care and that borrowing is to remain the same.

The options might be:

VAT	Income Tax	Pensions Spending	Health Care Spending
Decrease to 18%	Decrease to 25%	Leave as it is	Decrease by 15%
Decrease to 15%	Decrease to 20%	Increase by 5%	Decrease by 10%
Leave as it is	Leave as it is	Increase by 10%	Increase by 10%
Increase to 21%	Increase to 33%	Increase by 15%	Increase by 15%

Suppose the the average changes to each heading after voting were:

- VAT average vote: -8.75%
- Income Tax average vote: -12.5%
- Pensions Spending average vote: 6.25%

- Health Care Spending average vote: -1.25%

Let us now calculate the dot product  $\mathbf{q.n}$  from equation 3.2

$$86 \times 10^9 \times -0.0875 + 153 \times 10^9 \times -0.125 + -120 \times 10^9 \times 0.0625 + \\ -121 \times 10^9 \times -0.0125 + 2 \times 10^9 \times 0 = -32.6375 \times 10^9 = \alpha$$

The dot product  $\mathbf{n.n}$  from equation 3.2 is calculated as follows

$$(86 \times 10^9)^2 + (153 \times 10^9)^2 + (-120 \times 10^9)^2 + (-121 \times 10^9)^2 + (2 \times 10^9)^2 = 5.985 \times 10^{22} = \beta$$

In the above equations spending terms enter with negative sign and revenue terms enter with positive. By applying the equation 3.2 we find the feasible changes in tax and spending closest to the average vote

- VAT feasible change  $= -0.0875 - (\alpha/\beta)86 \times 10^9 = -4.05992\%$
- Income Tax feasible change  $= -0.125 - (\alpha/\beta)153 \times 10^9 = -4.15602\%$
- Pensions Spending feasible change  $= 0.0625 - (\alpha/\beta)(-120 \times 10^9) = -0.294297\%$
- Health Care Spending  $= -0.0125 - (\alpha/\beta)(-121 \times 10^9) = -7.84883\%$

The results are summarised as follows

	Average Vote	Feasible Change
VAT	-8.75%	-4.05992%
Income Tax	-12.5%	-4.15602%
Pensions	6.25%	-0.294297%
Health Care	-1.25%	-7.84883%

Let us now verify that the feasible changes satisfy the constraint in equation 5.2 by working out the error in £ were the tax rates and expenditures to be adjusted this way

$$((-0.0405992) \times 86 + \\ (-0.0415602) \times 153 + \\ (-0.00294297)(-120) + \\ (-0.0784883)(-121) \\ + 0 * 2) \times 10^9 = -£1100$$

It is evident that the result of the multiplication of the feasible changes by the corresponding amounts in pounds is a relatively very small value (not equal to 0 due to rounding error) therefore the feasible changes are consistent with balanced budget. In practice of course the adjustments of tax rates could not be this exact since they would have to be expressed in whole percentage terms.

# Appendix G

## HandiVote Screenshots

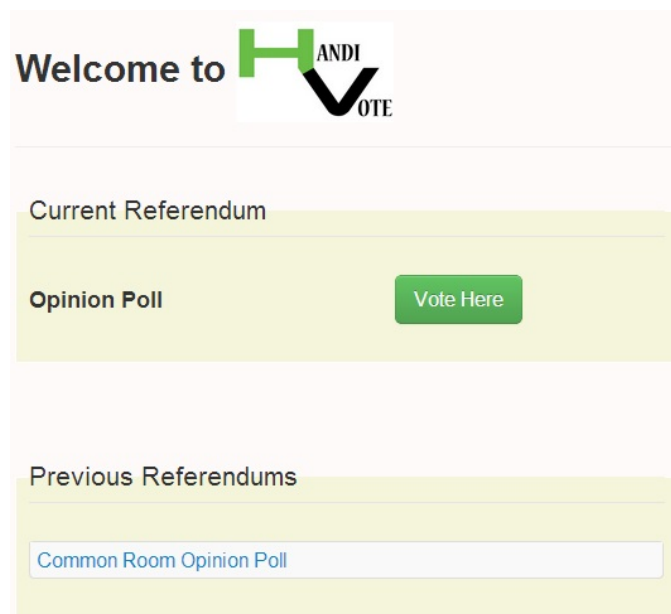


Figure G.1: HandiVote Homepage (index.php)

## Name The Robot

**Question 1.** What should we name the Robot?

Please select one...

- Arcteryx (Greek God of Clothing)
- Dexterous Blue
- The Smurf Bunny
- Segmentation Fold
- MARFF (Mechanical Automated Robot for Folding)

Barcode (the red code on your student card):

Please Note: Your anonymity is preserved. Matric Numbers will not be stored and Barcodes will be discarded after the referendum is over

Submit Vote

Figure G.2: HandiVote Voting Page (handivote.php)

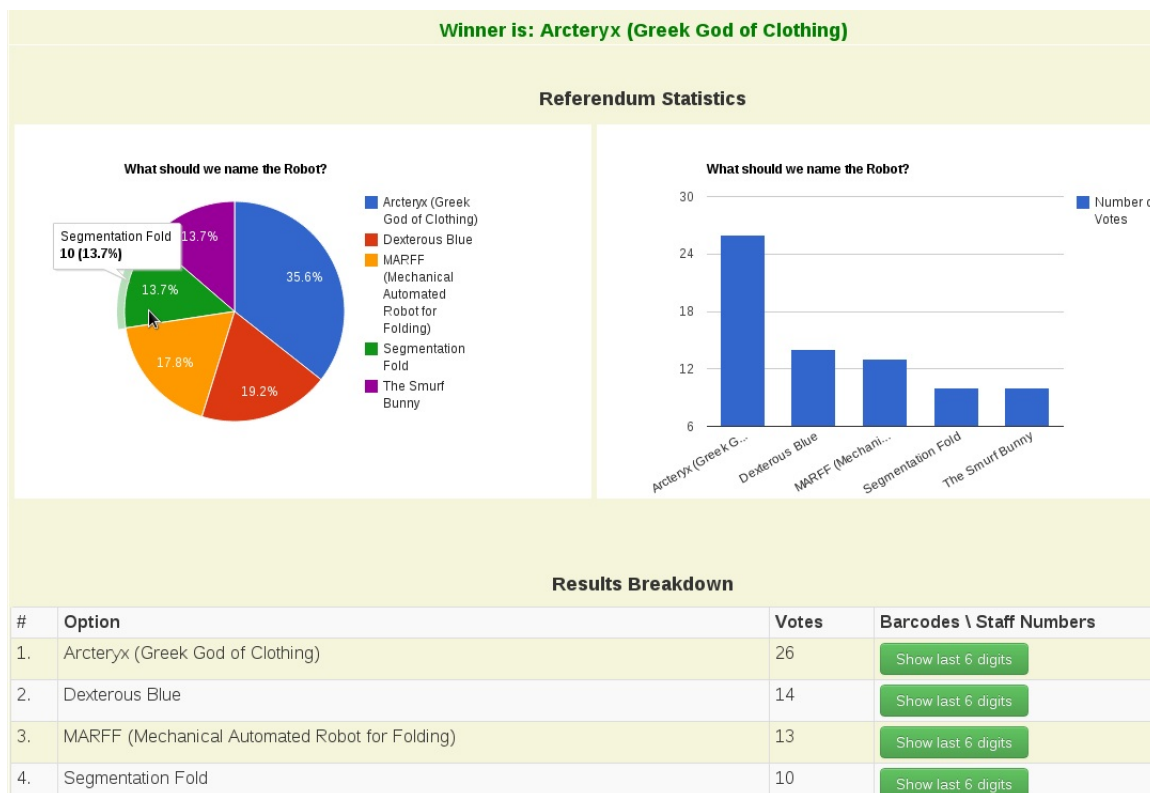




Figure G.3: HandiVote Result Page (view\_result.php)

51397799  
51397806  
51397810  
51397813  
51397816  
51397823  
51397830  
51397831  
51397832

Figure G.4: List of Barcodes (show\_barcode.php)

Welcome to  **H**ANDI  
**V**OTE

 **Thank you**

You have successfully submitted your vote on Fri Jan 11, 2013 16:50 pm.

Your IP Address is: 130.209.245.212

Please **do not** attempt to vote again, as this will invalidate your first and any subsequent votes.

Please come back to the HandiVote page to see the results and to verify your vote on the 17th January.

Figure G.5: "Thank You" Page (thankyou.php)

All referendums are listed below. Please note that **only 1 referendum can be live at any time**. Please schedule any new referendums after the end date of the previous one.

### Options

[Create New Referendum](#)

[Add Another Admin](#)

[Logout](#)

### Existing Referendums

Description	Start Date	End Date	Votes	Status
<a href="#">Name The Robot</a>	2012-11-01	2012-12-26	73	published
<a href="#">Budgetary Plebiscite</a>	2012-12-11	2013-01-20	20	published

Figure G.6: Admin Dashboard (administration.php)

Please note that only 1 referendum can be live at any time : Please schedule any new referendums after the end date of the previous one.

If you change the name of a referendum, you will have to delete the draft that you have created from the main page dashboard before you can save your changes.

## New Referendum

Title:\*

Start Date:\*

End Date:\*

Question 1\*

What kind of question is this going to be?

Question 2

What kind of question is this going to be?

Question 3

What kind of question is this going to be?

Question 4

What kind of question is this going to be?

Question 5


What kind of question is this going to be?

By how much will your revenue change for the next period?:

Revenue will   %

Figure G.7: New Referendum Form (new\_ref.php)



Welcome to 

---


## Opinion Poll

**Status:** not started  
**Start Date:** 2016-07-03  
**End Date:** 2016-08-07  
**Votes:** 0

**Question 1:** What is your opinion on this issue?  
**Option 1:** I agree  
**Option 2:** I disagree

[Back](#) [Delete](#) [Start Referendum](#)

Figure G.8: Referendum Overview Page (view\_referednum.php)

Welcome to 

## Add Administrator

Please fill in the details

First Name:\*


Surname:\*

Email:\*

Username:\*

Password:\*

Figure G.9: New Admin Details Form (add\_admin.php)

Welcome to 

Please log in:

Username:

Password:

Figure G.10: Admin Log In Page (login.php)

# Appendix H

## Test Cases

Test cases for the handivote.php page. These test cases test the voting functionality if the HandiVote system. They are executed in sequence:

1. If more than one referenda in the database, the algorithm selects and updates correct one.
2. Submit votes with all options, see if they come through to the database correctly, and the referendum result is incremented
3. Vote twice with same option, verify that void=0 in the database, a bad vote is inserted with reference *repeat\_vote*, the result is not increased
4. Vote twice with 1 or more different options, verify that void = 1, a bad vote is inserted with reference *repeat\_vote*, the result is decreased
5. Repeat steps 2-4 by voting via SMS
6. Repeat steps 2-4 by voting via a mix of SMS and votes submitted via the web interface
7. Vote via SMS with non existent option. A bad vote is inserted with reference *invalid\_sms\_option*, the result is not increased
8. Submit invalid credentials via the web interface. A bad vote is inserted with reference *failed\_credentials*, the result is not increased
9. Repeat the above step with SMS
10. Vote with an invalid option, then vote with a valid option, then vote with an invalid option again. The second invalid vote does not cause void to become 1 or the result to be decreased.
11. Attempt submitting a vote via the web interface without filling in all the fields. Error message is displayed and the vote is not submitted
12. Scan a QR code on a voter card and make sure it redirects to the correct page and populates the fields correctly

## Appendix I

# HandiVote Installation and Configuration Instructions

The following instructions are for installation on Windows.

- Download EasyPHP from <http://www.easyphp.org/download.php>

I am using version: EASYPHP E.DEVSERVER 12.1  
PHP 5.4.6 VC9, Apache 2.4.2 VC9  
MySQL 5.5.27  
PhpMyAdmin 3.5.2.2

- Install the EasyPHP package.
- Paste the HandiVote files in the folder EasyPHP-12.1/www
- Start the server by double clicking on the EasyPHP icon in the folder EasyPHP-12.1
- Right click on the EasyPHP icon that appears in the taskbar and select Administration. Open PhpMyAdmin. Create a database called handivote. Import the handivote.sql.
- The HandiVote index page is now available at 127.0.0.1:8080/index.php you can arrive at that page by typing it in the address bar or by right clicking on the EasyPHP icon on the taskbar and then selecting Local Web. The HandiVote system performs best in Chrome.
- To configure the connection to the database go to file **connection\_db.php**.
- The file **handivote.php** expects the path to the file to be /html/handivote.php. If it is not, then open the file **handivote.php** and change the path name on line 465 below the comment **/\*\* Configure Here \*/**.
- The image of the voting card displayed to the voters can be changed from the file **handivote.php**. The image is on line 526 under the comment **/\* CARD IMAGE - change from here if no longer relevant \*/**.

Alternatively, delete the old card image called **newcard.png** and name your new image **newcard.png**. The image will be replaced automatically.

- The message displayed to the voters on the voting page can be configured from file **handivote.php**. The message is on line 522 under the comment **/\* MESSAGE - change from here if no longer relevant \*/**.

## Appendix J

# HandiVote User Guide

Please note that the HandiVote system performs best in Chrome.

### **J.0.1 Logging in the Administration Dashboard**

Go to /login.php. Log in using the default username *admin* and default password *handivoteadmin*

### **J.0.2 Creating a referendum**

From the Admin Dashboard below, click on Create New Referendum.

All referendums are listed below. Please note that **only 1 referendum can be live at any time**. Please schedule any new referendums after the end date of the previous one.

### Options

[Create New Referendum](#)

[Add Another Admin](#)

[Logout](#)

### Existing Referendums

Description	Start Date	End Date	Votes	Status
<a href="#">Name The Robot</a>	2012-11-01	2012-12-26	73	published
<a href="#">Budgetary Plebiscite</a>	2012-12-11	2013-01-20	20	published

Figure J.1: Admin Dashboard

This will take you to the form for the new referendum:

Please note that only 1 referendum can be live at any time : Please schedule any new referendums after the end date of the previous one.

If you change the name of a referendum, you will have to delete the draft that you have created from the main page dashboard before you can save your changes.

## New Referendum

Title:\*

Start Date:\*

End Date:\*

Question 1\*

What kind of question is this going to be?

Question 2

What kind of question is this going to be?

Question 3

What kind of question is this going to be?

Question 4

What kind of question is this going to be?

Question 5

What kind of question is this going to be?

By how much will your revenue change for the next period?:

Revenue will   %

Figure J.2: New Referendum Form

Fill in the details of the new referendum. Keep in mind that only 1 referendum can be live at any time, therefore all referenda have to be scheduled in sequence. If you change the name of a draft referendum, you will need to delete the draft and then create the referendum again. Referenda cannot be scheduled in the past. You need to fill in at least 1 question with 2 options. For spending and tax questions you need to fill in current levels of tax and spending as well as the total revenue for the next period, as this is needed for the calculations.

Any error messages are displayed in red on top of the page as shown below. If errors are found, you will have to fill in again the dates of the referendum. If you had filled in any questions prior to the error message, you need to select the type of question you had selected before and the input will appear. For example you if had selected a simple question for Question 1, select a simple question again for Question 1 and the input will appear.



Figure J.3: Error Messages


Once all necessary details are entered you will be taken to the verification page. If you are happy to proceed with the new referendum, press Create Referendum. Otherwise press the Back button and modify the referendum.

The newly created referendum will appear on the Administration Dashboard under Existing Referenda with status "not started".

### J.0.3 Starting the referendum

From the Administration Dashboard click on the name of the referendum.



Welcome to 

All referendums are listed below. Please note that **only 1 referendum can be live at any time**. Please schedule any new referendums after the end date of the previous one.

Options

[Create New Referendum](#)  
[Add Another Admin](#)  
[Logout](#)

Existing Referendums

Description	Start Date	End Date	Votes	Status
<a href="#">Name The Robot</a>	2012-11-01	2012-12-26	73	published
<a href="#">Budgetary Plebiscite</a>	2012-12-11	2013-01-20	20	published

Figure J.4: Existing Referenda

This will take you to the below overview page. Click on the Start button. This will change the status of the referendum to "in progress". Please note that only referenda with status "not started" will have a Start button.

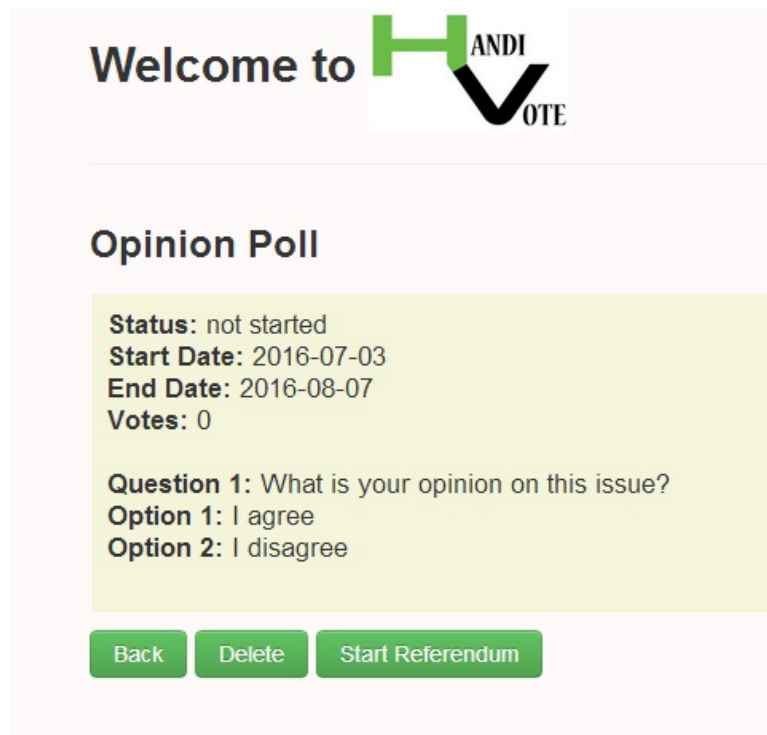


Figure J.5: Referendum Overview Page

#### J.0.4 Calculating results

This is the same process as with **Starting the Referendum** above.

From the Administration Dashboard click on the name of the referendum. This will take you to the referendum overview page. Click on the Calculate button. This will change the status of the referendum to "calculated\_result". Please note that only referenda with status "finished" will have a Calculate button.

#### J.0.5 Publishing the referendum

This is the same process as with **Starting the Referendum** above.

From the Administration Dashboard click on the name of the referendum. This will take you to the referendum overview page. Click on the Publish button. This will change the status of the referendum to "published". Please note that only referenda with status "calculated\_result" will have a Publish button.

#### J.0.6 Deleting a referendum

This is the same process as with **Starting the Referendum** above.

From the Administration Dashboard click on the name of the referendum. This will take you to the referendum overview page. Click on the Delete button. Please note that only referenda with status "draft" and "not started" can be deleted. Therefore the Delete button will not appear on referenda with any other status.

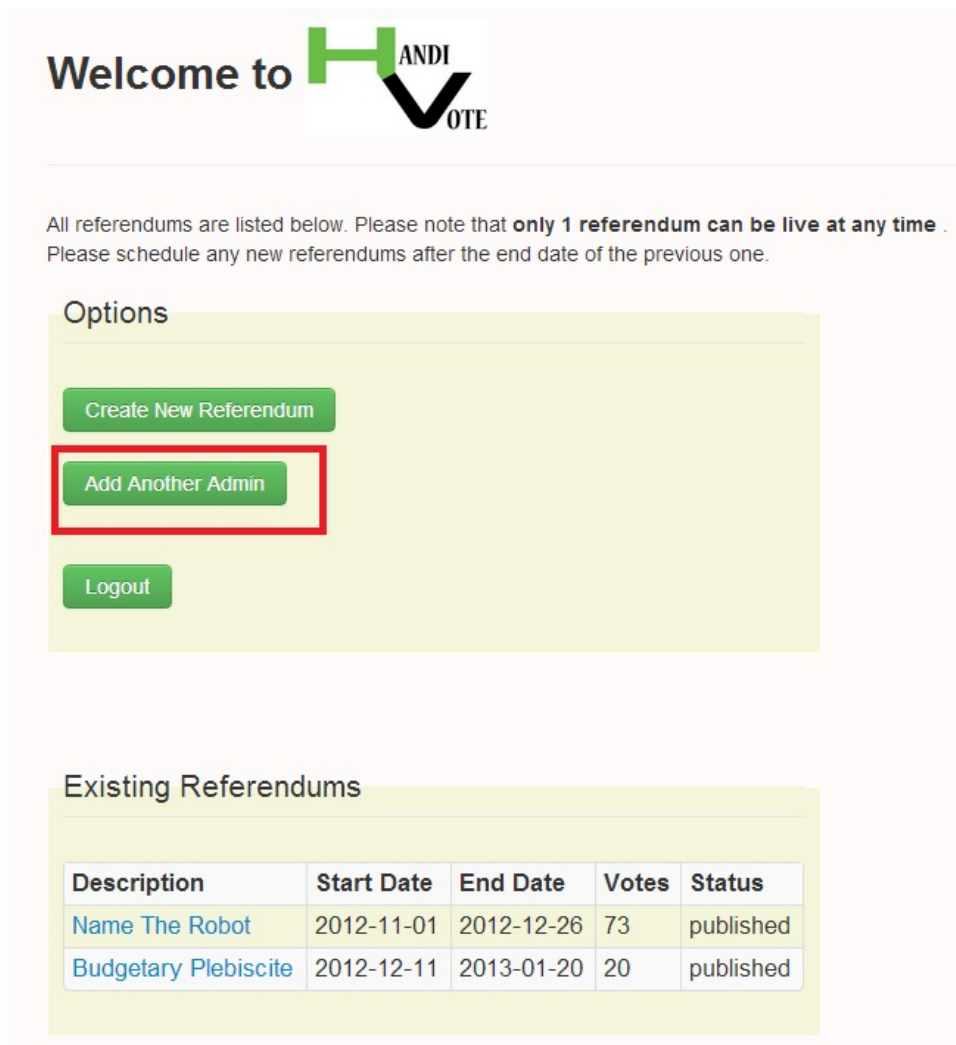
## J.0.7 Stopping a referendum

This is the same process as with **Starting the Referendum** above.

From the Administration Dashboard click on the name of the referendum. This will take you to the referendum overview page. Click on the Stop button. You cannot "pause" and "restart" the referendum so only press Stop when you wish to permanently close the referendum. This will change the status of the referendum to "finished". Please note that only referendum with status "in progress" will have a Stop button.

## J.0.8 Adding an admin

From the Administration Dashboard click on Add Another Admin.



Welcome to **ANDI VOTE**

All referendums are listed below. Please note that **only 1 referendum can be live at any time**. Please schedule any new referendums after the end date of the previous one.

### Options


- Create New Referendum
- Add Another Admin**
- Logout

### Existing Referendums

Description	Start Date	End Date	Votes	Status
<a href="#">Name The Robot</a>	2012-11-01	2012-12-26	73	published
<a href="#">Budgetary Plebiscite</a>	2012-12-11	2013-01-20	20	published

Figure J.6: Admin Dashboard

Fill in the form and press Submit Details:

Welcome to 

## Add Administrator

Please fill in the details

First Name:*	<input type="text"/>
Surname:*	<input type="text"/>
Email:*	<input type="text"/>
Username:*	<input type="text"/>
Password:*	<input type="text"/>

Figure J.7: New Admin Details Form

### J.0.9 Voting

Go to `index.php` and make your selection.

### J.0.10 View referendum

This is the same process as with **Starting the Referendum** above.

From the Administration Dashboard click on the name of the referendum. This will take you to the referendum overview page.

# Appendix K

## Status Report

### K.1 Overall Status

The software has met all of its requirements. This version of the software is stable.

### K.2 Major Deficiencies

- The user interface could be improved in terms of design and positioning of the graphs and charts.
- The file handivote.php has to be updated with the latest filepath for the software to run. Details are given in the Installation Instructions.
- The software is dependent on external services. These services are often unavailable. The software does not diagnose or indicate an external system failure. Instead it either fails or behaves inconsistently.
- If an error in the input to the web form in page new\_ref.php is encountered the page is refreshed and the input to drop down menus is lost while the input to text fields is retained.
- While verifying a referendum, if the Back button is pressed in Mozilla Firefox, input to drop down menus is lost while the input to text fields is retained. This problem does not exist in Chrome.
- A referendum can only be modified by pressing the Back button from the verifying page at the time of creation.

# Appendix L

## Summary Log

The projects went through the following main stages:

1. **September/October:** The problem was defined and the initial requirements were gathered. A project plan was approved.
2. **October:** The voter interface was delivered, through a series of paper and HTML prototypes and then implemented in PHP and JavaScript and tested.
3. **November:** The administrator interface was delivered, through a series of paper and HTML prototypes and then implemented in PHP and tested.
4. **November/December:** The algorithm to optimise the vote subject to budget constraint was implemented and tested with UK data.
5. **December:** The first evaluation of the software was organised.
6. **January:** The second evaluation of the software was organised. The project report was drafted.
7. **February:** The third referendum was organised. The project report was improved on.
8. **March:** The forth referendum was organised. The project report finalised.