

Appendix A

Glossary

A.1 Special Symbols

Mathematical Symbols

The following mathematical variable types are used in this thesis:

m A matrix (also: $m_{i,j}$ or \mathbf{m}_i)

v A vector or array (also v_i)

n A normalised vector

s A scalar

Other Symbols

The names of keys or functions on a text input device are represented in a monospace type in angled brackets, such as: <Space>. Individual characters are represented by the symbol printed in a monospace type, such as: a.

A special graphical notation is used to describe the finger patterns used to create a chord on the Chording Glove. The diagram uses filled or unfilled circles positioned in the approximate positions of the fingertips on the right hand. The thumb is lowered and on the left, and the other fingers are raised, with the order: index, ring, middle, and little. A filled circle means the finger is pressed, and an empty circle indicates that the finger is not. For example, the chord $\circ^\circ \bullet \bullet^\circ$ is generated by pressing the middle and ring fingers.

A.2 Glossary of Physiological Terms

The *anatomical position* is the standard orientation of the body from which all directions and motions are defined. In this position, the person is standing, with the arms down, feet pointing forward, and the thumbs pointing outward so that the palms face forward. Palastanga et al. (1990), pages 2–7 provides a good summary of the basic anatomical terminology.

The following physiological terms are used frequently in this thesis:

abduction A movement in the *lateral* direction, i.e. outward from the centre of the body. The opposite of *adduction*.

adduction A movement in the *medial* direction, i.e. towards the centre of the body. The opposite of *abduction*.

anterior In front of, or towards the front. For example, the nose is on the *anterior* part of the face. Also called *ventral*. The opposite of *posterior*.

deep The direction inward from the surface of the skin. The opposite of *superficial*.

distal The direction away from the root of a limb. The opposite of *proximal*.

dorsal Behind, or towards the rear. Also called *posterior*. The opposite of *ventral*.

extension Returning a joint to the neutral position, or moving beyond the neutral position in the opposite direction of *flexion*.

- flexion** Bending a joint so that two anterior or posterior faces are brought together. The opposite of *extension*.
- lateral** The direction outward from *median plane*, ie out from the centre of the body. The opposite of *medial*.
- medial** The direction toward the *median plane*, ie towards the centre of the body. The opposite of *lateral*.
- median plane** The plane of symmetry between right and left halves of the body. Also called the *sagittal plane*.
- posterior** Behind, or towards the rear. For example, the spine is on the *posterior* part of the trunk. Also called *dorsal*. The opposite of *anterior*.
- pronation** Rotating the forearm along the axis of the arm, so that the palm faces backwards. The opposite of *supination*.
- proximal** The direction toward from the root of a limb. The opposite of *distal*.
- radial deviation** *Abduction* of the wrist, ie bending the wrist in the direction of the thumb. The opposite of *ulnar deviation*.
- sagittal plane** The plane of symmetry between right and left halves of the body. Also called the *median plane*.
- superficial** The direction toward the surface of the skin. The opposite of *deep*.
- supination** Rotating the forearm along the axis of the arm, so that the palm faces forward. The opposite of *pronation*.
- ulnar deviation** *Adduction* of the wrist, ie bending the wrist in the direction of the little finger. The opposite of *radial deviation*.
- ventral** In front of, or towards the front. Also called *anterior*.

Appendix B

Relative Character Frequency for Keymap Design

Character probabilities were calculated by counting the appearances of each of the ASCII characters found in a large amount (596648 characters) of text in various formats which were considered to be likely to be the sort of text which is entered by hand (as opposed to computer generated). The breakdown of text types is as follows: (from most used to least).

1. Informal text (email, internet news posts, etc)
2. Formal text (papers, memos, etc)
3. C code
4. Theatre scripts
5. Recipes
6. Bibliographies
7. X Resources
8. Telephone numbers
9. Street Addresses

The following tables show the probabilities of each characters. <Space> and <Return> were omitted from the lists due to their high relative frequencies.

Table B.1: Character probability sorted by ASCII code

% Probability	Char.	% Probability	Char.	% Probability	Char.
0.835	tab	0.511	A	5.916	a
0.104	!	0.269	B	1.367	b
0.238	”	0.499	C	2.351	c
0.068	#	0.360	D	2.823	d
0.021	\$	0.435	E	9.436	e
0.054	%	0.249	F	1.739	f
0.057	&	0.180	G	1.863	g
0.364	,	0.215	H	3.484	h
0.607	(	0.574	I	5.438	i
0.609	)	0.080	J	0.123	j
0.709	*	0.129	K	0.859	k
0.131	+	0.448	L	3.273	l
1.104	,	0.297	M	2.035	m
1.224	-	0.343	N	5.569	n
1.830	.	0.309	O	6.564	o
0.167	/	0.269	P	2.043	p
0.546	0	0.048	Q	0.090	q
0.441	1	0.357	R	5.545	r
0.285	2	0.552	S	4.688	s
0.223	3	0.612	T	6.736	t
0.148	4	0.178	U	2.335	u
0.161	5	0.110	V	0.827	v
0.138	6	0.190	W	1.168	w
0.119	7	0.353	X	0.451	x
0.116	8	0.112	Y	1.491	y
0.138	9	0.009	Z	0.136	z
0.703	:	0.142	[	0.067	{
0.399	;	0.131	\	0.033	|
0.108	<	0.142	]	0.067	}
0.957	=	0.001	^	0.012	~
0.189	>	0.456	_		
0.084	?	0.008	‘		
0.035	@				

Table B.2: Character probability in order of decreasing probability

% Probability	Char.	% Probability	Char.	% Probability	Char.
9.446	e	0.552	S	0.138	9
6.736	t	0.546	0	0.138	6
6.564	o	0.511	A	0.136	z
5.916	a	0.499	C	0.131	\
5.569	n	0.454	-	0.131	+
5.545	r	0.451	x	0.129	K
5.438	i	0.448	L	0.123	j
4.688	s	0.441	l	0.119	7
3.484	h	0.435	E	0.116	8
3.273	l	0.397	;	0.112	Y
2.823	d	0.364	'	0.110	V
2.351	c	0.360	D	0.106	<
2.335	u	0.357	R	0.104	!
2.043	p	0.353	X	0.090	q
2.035	m	0.343	N	0.084	?
1.863	g	0.309	O	0.080	J
1.830	.	0.297	M	0.068	#
1.739	f	0.285	2	0.067	{
1.491	y	0.269	B	0.067	}
1.367	b	0.262	P	0.057	&
1.224	-	0.249	F	0.054	%
1.168	w	0.238	”	0.048	Q
1.104	,	0.223	3	0.035	@
0.957	=	0.215	H	0.033	|
0.859	k	0.190	W	0.021	\$
0.836	tab	0.189	>	0.012	~
0.827	v	0.180	G	0.009	Z
0.709	*	0.178	U	0.008	‘
0.703	:	0.167	/	0.001	^
0.612	T	0.161	5		
0.609	)	0.148	4		
0.607	(	0.142]		
0.574	I	0.142	[

Table B.3: Character probability by type

Lower case letters (default)		Upper case letters (CAPS)		Numerical characters (NUM)		Punctuation (NUM + CAPS)		Control characters (CTRL)	
Return		Return		Return		Return			
Space		Space		Space		Space			
Backspace		Backspace		Backspace		Backspace			
9.44	e	1.83	.	1.83	.	0.71	*	0.84	tab
6.74	t	1.10	,	1.22	-	0.70	:		
6.56	o	0.61	T	1.10	,	0.45	-		
5.92	a	0.57	I	0.96	=	0.40	;		
5.57	n	0.55	S	0.71	*	0.36	'		
5.55	r	0.51	A	0.61	)	0.24	”		
5.44	i	0.50	C	0.61	(	0.19	>		
4.69	s	0.45	L	0.55	0	0.13	\		
3.48	h	0.43	E	0.44	1	0.11	<		
3.27	l	0.36	D	0.29	2	0.10	!		
2.82	d	0.36	R	0.22	3	0.08	?		
2.35	c	0.35	X	0.17	/	0.07	#		
2.34	u	0.34	N	0.16	5	0.07	{		
2.04	p	0.31	O	0.15	4	0.07	}		
2.04	m	0.30	M	0.14	]	0.06	&		
1.86	g	0.27	B	0.14	[	0.05	%		
1.83	.	0.26	P	0.14	9	0.04	@		
1.74	f	0.25	F	0.14	6	0.03	|		
1.49	y	0.21	H	0.13	+	0.02	\$		
1.37	b	0.19	W	0.12	7	0.01	~		
1.17	w	0.18	G	0.12	8	0.01	‘		
1.10	,	0.18	U	0.001	^	0.001	^		
0.86	k	0.13	K						
0.83	v	0.11	Y						
0.45	x	0.11	V						
0.14	z	0.08	J						
0.12	j	0.05	Q						
0.09	q	0.01	Z						
31 characters		31 characters		25 characters		25 characters		1 character	

Appendix C

The Chording Glove Hardware

C.1 Introduction

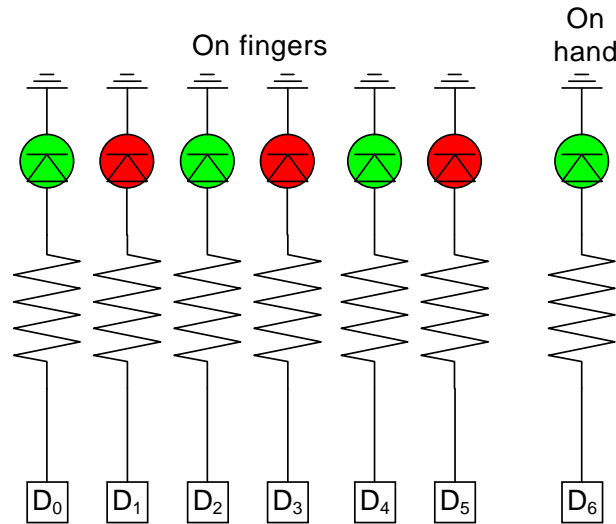
This appendix describes the sensors and indicators used in the Chording Glove. The design and circuitry are described in detail in order to facilitate experimentation by other investigators. In addition, sensor designs that were tested, but not used in the final version are included here so future researchers will know that the designs are insufficient.

C.2 LED Outputs

The LEDs are used to show the current shift state. The LEDs are all independent in the hardware and can be turned on and off in any manner. This could be additionally used to alert the user to some error. To save space, 2.21mm square sub-miniature LEDs were used. These had an intensity of about 3mcd, which is bright enough to be easily noticed. The circuit diagram is shown in Figure C.1.

There are two groups of LEDs. Six on the index finger and one on the back of the hand. The index finger LEDs are divided into 3 groups of two LEDs, one red and one green. Only one of a group (i.e. red or green) should be on at a time. The green indicates the shift is on and will operate on the next character. The red indicates that the shift is locked and will stay on until turned off. These LEDs are located next to the shift buttons (Figure 3.1). The LED on the back of the hand is near the AutoCaps key. When AutoCaps is on the LED is on, when off the LED is off. The hardware design leaves room for future use of an eighth LED.

Figure C.1: Circuit diagram of the LED setup. D_n is the n th output bit. Resistor values are 180Ω .



C.3 Finger Sensors

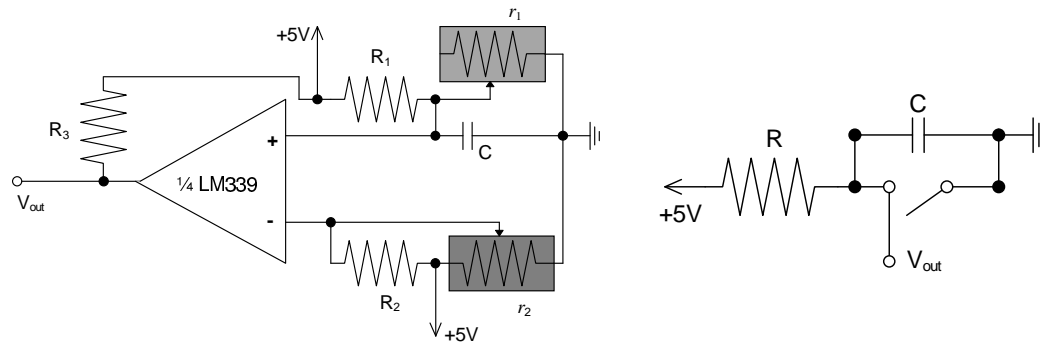
Ten designs were tested for the finger sensors of the Chording Glove. These sensors were either digital or analogue. All the analogue sensors had the same circuit diagram, as shown in Figure C.2(a). In this diagram, r_1 is the sensor, with a variable resistance and r_2 is a potentiometer which sets the cutoff voltage for the sensor. These are fed into a comparator to yield a digital on/off reading for the sensor. The capacitor is used for a low pass filter to remove excess noise. The resistor R_3 is used to pull up the comparator

output. The digital sensors has the same circuit diagram which is shown in Figure C.2(b). An open circuit gives $v_{out} = 5V$ and a closed circuit grounds v_{out} . The capacitor is used for a low pass filter to eliminate bounce noise.

The ten sensor designs were as follows:

1. Double foil plates.
2. Interlaced foam.
3. Foil plate and single laced foam.
4. Single laced foam and conductive unlaced foam with foil backing.
5. Single laced foam and foil cover.
6. Moulded resistive foam with foil backing.
7. Moulded low density resistive foam with foil backing.
8. Resistive foam with silvered faces.
9. Resistive foam with foil backing.
10. Hard copper plate.

The Resistive Foam with Foil Backing sensors were initially used in the experiment, but were soon changed after they were found to be long-term unstable. They were replaced by the Hard Copper Plate sensors which were successfully used for the remainder of the experiments.



(a) The analogue finger sensor. $C=22pF$, $R_1=1k\Omega$, $R_2=430k\Omega$, $R_3=100k\Omega$, r_1 is the variable resistance sensor, and r_2 is a $20k\Omega$ potentiometer

(b) The digital finger sensor. $C=22pF$ and $R=56k\Omega$

Figure C.2: Circuit diagrams for the finger sensors

C.3.1 Double Foil Plates

Description The sensor consists of two aluminium foil plates separated by foam on the edges. The centre of each plate bulges out due to the placement of the wires, which are taped onto the foil (Figure C.3).

Operation Pressing with a finger causes the bump in the middle of one plate to hit the bump in the middle of the other plate, completing the circuit.

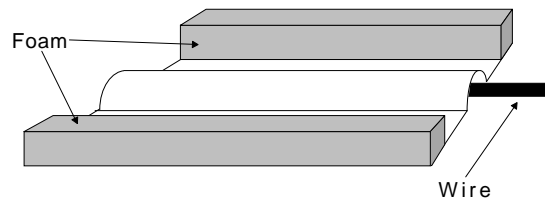


Figure C.3: Double Foil Plate Finger Sensor. For clarity, the top plate is not shown in this diagram.

Advantages Very easy to make.

Problems

- The sensor does not have necessary accuracy. It only works on well-defined presses near the middle. It is not sensitive near the edges.
- It is too small to sense the entire fingertip, and too big to use multiple sensors on one finger.

C.3.2 Interlaced Foam

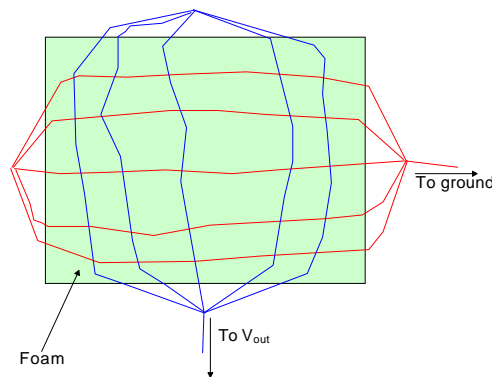


Figure C.4: Interlaced Foam Finger Sensor

Description The sensor is made from a rectangular piece of foam about the size of the fingertip. Several small, flexible threads of wire are separated and sewn through the foam. One group of wires are sewn horizontally on one side of the foam, the others are sewn vertically on the other side. Each group meets at the end of the foam. Each groups meets outside the foam and are bundled together to make one wire (Figure C.4).

Operation Pressing anywhere on the foam with a finger causes the wires to touch completing the circuit.

Advantages

- Relatively easy to make.
- Should be accurate over the entire surface, as compared to the first sensor attempted.

Problems

- It is easy to make, but in practice it is hard to standardise. Threads do not go through entirely straight. This and irregularities (holes or bunching up) in the foam causes areas of extra sensitivity or no sensitivity.

- It is easy for wires to touch accidentally. If this happens it is very hard to fix.
- It is not flexible enough to mould to the shape of a fingertip.

C.3.3 Foil Plate and Single Laced Foam

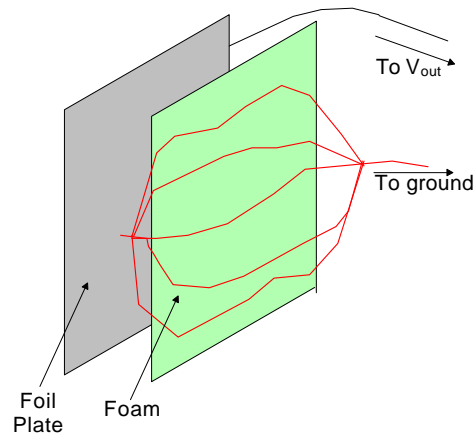


Figure C.5: Foil Plate and Single Laced Foam Finger Sensor

Description The sensor is made from two parts. The main part is a rectangular piece of foam about the size of the fingertip. The wire connected to it is divided into several small flexible threads. These threads are sewn through the foam, lengthwise, very close to the surface. The other wire is connected to the back of a strip of aluminium foil the same size as the foam. The foam is taped to the front of the foil (Figure C.5).

Operation Pressing anywhere on the foam with a finger causes the wires in the foam to touch the foil, completing the circuit.

Advantages

- Relatively easy to make
- There are no insensitive areas on the sensor.

Problems

- In practice it is hard to standardise. Irregularities (holes or bunching up) in the foam causes areas of extra sensitivity or no sensitivity.
- The sensor not flexible enough to mould to the shape of a fingertip.

C.3.4 Single Laced Foam and Conductive Unlaced Foam with Foil Backing

Description Two aluminium foil plates are separated by a high density resistive foam, and a non-conductive foam, laced with wires (Figure C.6).

Operation When the sensor is pressed, the wires touch the conductive foam, completing the circuit.

Advantages None.

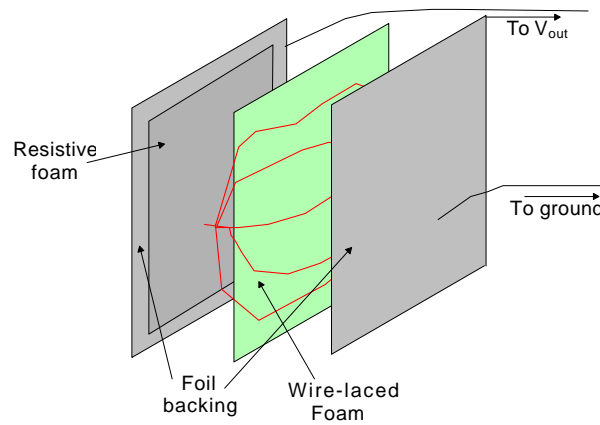


Figure C.6: Single Laced Foam and Conductive Unlaced Foam with Foil Backing Finger Sensor

Problems The wires in the foam cannot be made close enough to the surface to reach the foam when compressed. As a consequence the design cannot work.

C.3.5 Single Laced Foam and Foil Cover Finger Sensor

Description The first half of the sensor is a rectangular piece of foam about $1\frac{1}{2}$ inches by 1 inch. The wire connected to it is divided into several small flexible threads. These threads are sewn through the foam, lengthwise, just below the surface. This is sewn onto the glove covering the fingertip. The other half of the sensor is foil, moulded to the shape of the fingertip and placed over the foam. A second wire is taped to the foil (Figure C.7).

Operation Pressing with a finger causes the foil to touch the wires in the foam, which completes the circuit.

Advantages

- This is the first design shaped specifically for the fingertip.
- There are no insensitive areas on the fingertip.

Problems

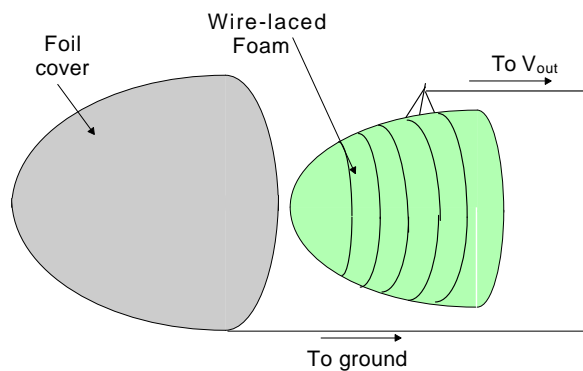


Figure C.7: Single Laced Foam and Foil Cover Finger Sensor

- It covers the entire fingertip, therefore it does not leave room for any shift keys on the last knuckle of the index finger
- Irregularities in the size of the gaps in the foam cause too many unwanted circuit connections.

C.3.6 Moulded Resistive Foam with Foil Backing Finger Sensor

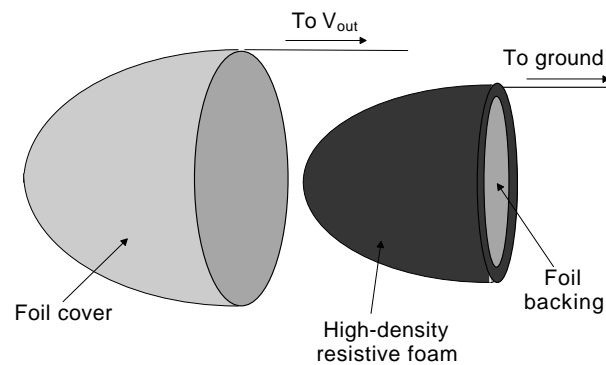


Figure C.8: Moulded Resistive Foam with Foil Backing Finger Sensor

Description The sensor is made from a resistive foam shaped to the shape of a fingertip. There are two aluminium foil plates, one on the inside and one on the outside. A wire is attached to each foil plate (Figure C.8).

Operation Pressing the sensor with a finger causes the foam to compress, lowering the resistance. This was tried with both a Schmitt Trigger (with fixed positive and negative voltages) and a double voltage divider (Figure C.2(a)). The latter was found to work better.

Advantages

- Easy to make
- Adjustable after making
- The sensor is not connected to the glove, making it easily fixed and interchangeable

Problems

- A large number of components are necessary to use the sensor
- Since the sensor covers the entire fingertip, finger motions can set it off.

C.3.7 Moulded Low Density Resistive Foam with Foil Backing

Description The sensor is made from a low-density resistive foam moulded to the shape of a fingertip. There are two aluminium foil plates, one on the inside and one on the outside. A wire is taped to each foil plate (Figure C.9).

Operation Pressing with a finger causes the foam to compress, lowering the resistance. The resistance is detected by a double voltage divider (Figure C.2(a)).

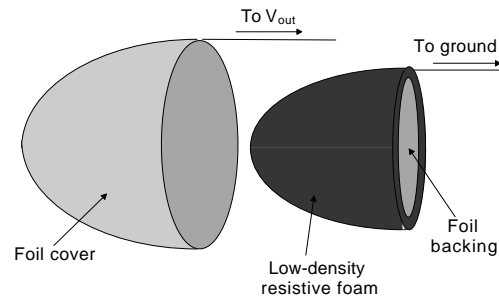


Figure C.9: Moulded Low Density Resistive Foam with Foil Backing Finger Sensor

Advantages

- Easy to make
- Adjustable after making.
- The sensor is not connected to the glove, so it is easily fixed and interchangeable.
- The sensor is more sensitive and less fragile than the high-density foam.

Problems

- The sensor requires more additional hardware than a digital sensor.
- Since the sensor covers the entire fingertip, finger motions can set it off.

C.3.8 Resistive Foam with Silvered Faces

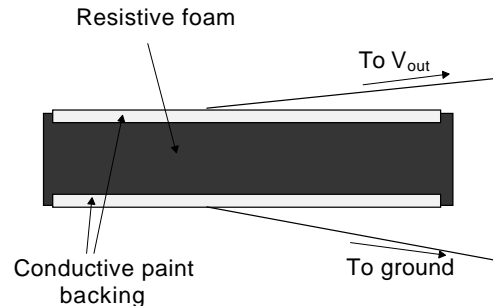


Figure C.10: Resistive Foam with Silvered Faces Finger Sensor

Description The sensor is made from a small rectangle of resistive foam which is coated with conductive paint on both sides. Wire is taped to each side. The foam is then sewn on the fingertip (Figure C.10).

Operation Pressing the sensor with a finger causes the foam to compress, lowering the resistance. This is detected by the change in voltage across a voltage divider.

Advantages

- Easy to make
- Adjustable after making
- Movements do not set it off

Problems

- The sensor requires more additional hardware than a digital sensor.
- Since the sensor is small some finger presses may go unnoticed.

C.3.9 Resistive Foam with Foil Backing

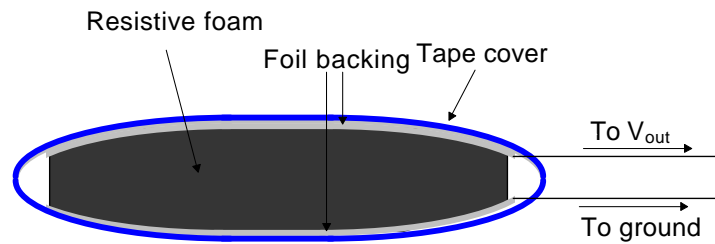


Figure C.11: Resistive Foam with Foil Backing Finger Sensor

Description A layer of foil is taped to the top and bottom of a small rectangle of resistive foam. Wire is taped to each side (Figure C.11).

Operation Pressing the sensor with a finger causes the foam to compress, lowering the resistance. This is detected by the change in voltage across a voltage divider.

Advantages

- Easy to make.
- Adjustable after making.
- Movements do not set it off.
- If wires are pulled out, they can be easily replaced.
- Weaker fingers can use thicker foam for more sensitivity.

Problems

- The sensors require a comparator and potentiometer in order to use.
- The wires are very easy to pull out.
- Since it is small, some finger presses may go unnoticed.
- The resistance in the foam is temperature dependent. The longer it is used, the more the resistance changes. The heating comes from a combination of internal heating due to the resistance and external heating from the body heat of the finger. As a result potentiometers which control the threshold level must be constantly changed during use. The resistance eventually goes beyond the range of the potentiometers, rendering the sensor useless.

This sensor was the one initially used in the experiments. The temperature dependency was only discovered after the first few sessions. After this was discovered it was replaced by the next sensor.

C.3.10 Hard Copper Plate

Description Two springs connect a pair of small rectangular plastic plates. Thin sheets of copper are glued to each of the plastic backing plates. Wires are soldered to the copper plates. Additional solder acts as a conductive extension of the copper plates. The entire sensor is encased in insulating tape to prevent damage and facilitate connecting to the glove (Figure C.12).

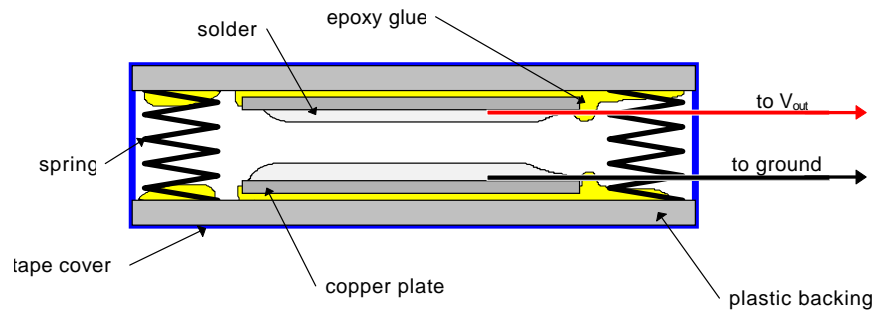


Figure C.12: Hard Copper Plate Finger Sensor

Operation Pressing the sensor with a finger causes the springs to compress and the copper solder on top of the copper plates to complete the circuit. Bounce noise is removed by a filter in the hardware Figure C.2(b).

Advantages

- Easy to make.
- The height of the solder surface can be adjusted slightly to alter sensitivity.
- Movements do not set it off.
- Wires are attached with epoxy and solder and should not be able to be disconnected short of major breakage.

Problems

- Extra capacitors are necessary to remove bounce noise.
- Flat sensors do not mould to the fingertip shape well causing stress on the thread connecting them to the glove.
- The components are large and bulky, making the sensor somewhat inconvenient to use.
- There is a layer of solder on top of the metal plate. When the solder is initially put on, some of the flux forms a thin layer on top. After repeated use, the flux fractures, forming what appears to be a white powder, at the contact points. This acts as an insulator and prevents contact between the plates, causing the sensor to become difficult or impossible to use. The excess flux can be easily removed by burning off with a soldering iron. The more flux removed, the less is left to cause a problem. This problem disappears after long term use.
- Repeated heating of the metal pads (to remove flux, repair dislodged wires, etc) can cause the plastic backing to deform.
- There is not enough room on the thumb for two sensors.
- These are the most expensive of all the attempts at finger sensors.

These sensors replaced the Resistive Foam with Foil Backing sensors in the experiment, and were found to function adequately.

C.4 Shift Buttons

Two designs were tested for the shift buttons:

1. Taped aluminium foil plates.
2. Taped copper foil plates.

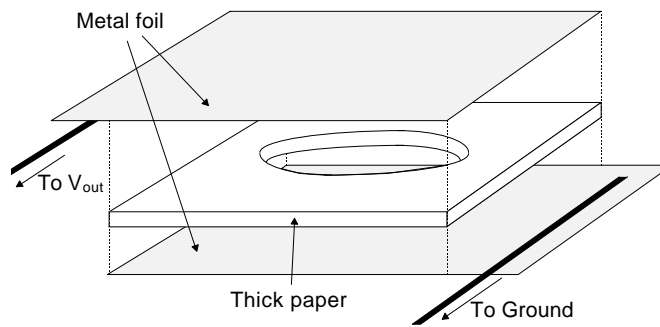


Figure C.13: Taped Aluminium Foil Plate Shift Button

C.4.1 Taped Aluminium Foil Plates

Description The button consists of two aluminium foil plates separated by a thick piece of paper with a hole cut out of the middle. The wires are connected to the foil at the sides. The button is taped together with blue PVC tape (Figure C.13).

Operation Pressing the button with a finger causes the foil plates to connect, completing the circuit.

Advantages

- Very easy to make
- Accurate

Problems

- No tactile feedback
- The buttons are too fragile to handle long term usage because the wires cannot be soldered to the aluminium, and consequently keep pulling loose.

C.4.2 Taped Copper Foil Plates

Description Two copper foil plates are separated by a thick piece of paper with a hole cut out of the middle. The wires are soldered to the foil at the sides. The button is covered with blue PVC tape. The setup is the same as for the Taped Aluminium Foil Plates (Figure C.13).

Operation Pressing the button with a finger causes the foil plates to connect, completing the circuit.

Advantages

- Very easy to make
- Accurate
- Wires will not pull out
- Stable enough for long term usage

Problems

- No tactile feedback

C.5 Function Keys

The function keys use the same Taped Copper Foil Plates buttons as the shift buttons (Figure C.13).

Appendix D

The Chording Glove Experiment Details

This appendix explains in detail various aspects of the Chording Glove experiment. These are: the questionnaires, the tutorial, and the chording sessions.

D.1 Questionnaires

D.1.1 Preliminary Questionnaire for the Glove Text Input Experiment

Figures D.1–D.3 shows the preliminary questionnaire used to determine subject suitability for the glove text input experiment. Boxed text explains the rationale behind asking the question.

D.1.2 Daily Questionnaire for the Chording Glove Experiment

The questionnaire in figure D.4 is used to determine the subjects reaction to the glove after each session. The boxed text explains which features of the Chording Glove this is trying to measure.

Figure D.1: The Preliminary Questionnaire: Cover page

The point of this experiment is to see how fast people learn to use a new type of keyboard. The experiment consists of one introductory session and ten practice sessions.

In the introductory session you will learn how to use the keyboard. This will take approximately one hour, possibly longer. You will not be paid for the introductory session.

The practice sessions consist of text entry with the keyboard for approximately one hour (with three breaks). You will be paid £1.50 at the end of the hour.

If you attend all the sessions you will be given a bonus of £15

In order to do the experiment you need to have eleven days in which you can come to the Queen Mary and Westfield College campus on Mile End Road. The days to now have to be in a row, but you should come at least once every three days. The experiments take place in Room E200 of the main building.

If you still want to take part in the experiment, please fill out the following questionnaire. This will determine if you will be a viable subject. More people have responded than I need so selection will be done based on your answers and whoever replies first. I will get back to you as soon as I can to schedule times for the experiment.

Thank you for your time.

Bob Rosenberg

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Figure D.2: The Preliminary Questionnaire: Page 1

Preliminary Questionnaire for the Glove Text Input Experiment

Name: _____ For record keeping only

Native Language: _____ People who are not proficient in English may have a harder time performing the tasks in the experiment.

Sex: _____ (Male / Female) These are asked to help answer any anomalies in the subject's performance

Do you wear glasses or contact lenses? (Yes / No)

Are you right or left handed? (Right / Left) Left handed subjects cannot be used because the glove is built for the right hand only

Have you ever experienced any repetitive strain injury in your hand or arm?
(for example: tendonitis, carpal tunnel syndrome, etc)

(Yes / No) This is to help account for muscle strain measurements

Are you experienced at any musical instruments? (Yes / No)
If yes: Which ones and how well do you know them?

Knowledge	List Instrument Here
1. Vague knowledge	
2. ...	
3. Can play a few tunes	
4. ...	
5. Proficient	

Do you know (even remotely) any sign languages? (Yes / No)
Which ones and how well?

Knowledge	List Languages Here
1. A few words or letters	
2. ...	
3. Enough to get by	
4. ...	
5. Fluent	

These are to help answer any possible anomalies in the learning rate.

Figure D.3: The Preliminary Questionnaire: Page 2

How experienced are you at typing on a normal (QWERTY) keyboard?

How experienced?	tick one
0. Never used one	0
1. Hunt and peck	1
2. A few times per week	2
3. Enough to get by	3
4. Some touch typing	4
5. Very good at touch typing (over 100 wpm)	5

Subjects should not have too much experience on a QWERTY keyboard

Give an approximation of how fast you can type (in words per minute)

This is to compare with their chording speed

How often do you type on a keyboard?

How often?	tick one
0. Never	0
1. Almost never	1
2. A few times per week	2
3. Less than 5 hours total in one week	3
4. At least one hour per day	4
5. Several hours per day	5

This is to help answer questions relating to typing injuries

Have you ever used an alternative keyboard?

(e.g. Dvorák, Microwriter, Apple Adjustable Keyboard, Newton, etc.)

(Yes / No)

Knowledge	List Keyboards here
0. Never	
1. Almost never	
2. A few times per week	
3. Less than 5 hours total in one week	
4. At least one hour per day	
5. Several hours per day	

Subjects with experience on chord keyboards should not be used

Figure D.4: The Daily Questionnaire

Input Experiment

Do you have any pain in your hands or arms?

1. No pain at all	1
2. ...	2
3. Somewhat sore/tired	3
4. ...	4
5. Very sore/tired	5

Muscle strain

Do you feel you have chorded too much, or could you chord for longer?

1. Too much	1
2. ...	2
3. Just about right	3
4. ...	4
5. Could continue for longer	5

Fatigue

What did you like best about chording?

User preferences

What did you like least about chording?

User preferences

Do you find chording more or less comfortable than typing?

1. Much less comfortable than typing	1
2. ...	2
3. The same as typing	3
4. ...	4
5. Much more comfortable than typing	5

User preferences

Do you find chording more or less comfortable than writing?

1. Much less comfortable than writing	1
2. ...	2
3. The same as writing	3
4. ...	4
5. Much more comfortable than writing	5

User preferences

Given the opportunity, would you want this for personal use?

1. Never!	1
2. ...	2
3. I'd use it sometimes	3
4. ...	4
5. I'd definitely want it	5

User preferences

D.2 The Tutorial

The following is the chord keyboard tutorial. This includes the handouts, programme and the script for the experimenter. An arrow (→) appears whenever the subject is prompted for a response.

The subject is handed two papers. The first is the keymap (Table 4.1). The second is the list of chords based on hand motions (Figure 3.4).

Experimenter: This is a tutorial to help you learn to type using chords. This is called chording. Feel free to ask any questions you may have as we go along. A chord is made by simultaneously pressing one or more fingers against a surface. The combination of fingers determines what letter is typed.

Experimenter: This (*point to 1st paper*) lists all the chords. The first column is the finger combination. A filled dot means the finger is pressed. An empty dot means the finger is not pressed. The rest of the columns show which chord is made, depending on which shifts are on.

Experimenter: The shift keys are located on the side of the index finger. (*point*) Pressing a shift will turn it on for the next one letter typed. Pressing the shift twice, rapidly, (like double-clicking a mouse) will lock the shift on. The shift will then stay on until pressed again. There are two lights by each shift which tell you the state. No lights, mean the shift is off, the green light mean it's on, but only for the next letter. If the red light is on, the shift is locked. Note that the shift does not turn off when you type <Space>, <BackSpace>, or <Return>.

Experimenter: The third button on the side of the index finger operates the help window (*point*). While the button is pressed the help window will be open. You don't need to use this for the tutorial unless you really want to, as you have this (*point to 1st paper*) to look at. During the experiment you won't have this, so you will have to use the help button.

Experimenter: When the first shift is on, the glove is in the *upper case* mode. All letters will be capitalised. <Space>, <BackSpace>, <Return>, <Period>, and <Comma> are unaffected. The second shift turns on the *number and math* mode. All the letters are turned into number and mathematical symbols such as <Plus> and <Minus>. Note that <Minus> is the same as <Hyphen>. When both shifts are on together the glove is in *punctuation* mode. This is all the punctuation keys that are above the numbers on the normal keyboard.

Experimenter: This (*point to 2nd paper*) lists all the chords which are similar in shape to the letters they make. You will use this in the tutorial. Practice using the glove until you feel you are ready to start the tutorial. Experiment with different hand positions, such as flat horizontal (*show*) or vertical (*show*). Tell me when you are ready. (*experimenter must press <Escape> on the **keyboard** to continue with the tutorial*)

Experimenter: In the tutorial you will be asked to type all the characters, followed by one or more short phrases. When you are done with each line press <Return>. Remember to type exactly what it tells you. It may not left you continue until you get the line correct. You will know this has happened, when you press return and nothing happens. Any questions before you begin?

***** The Basic Chords *****

In this section you will be introduced to the basic chords and how to use them to make lower case letters.

Using the chord list as your guide, type the following chords:
space, backspace, and return

→

Now type full stop (period) and comma. Note that the comma is the same chord as the full stop, with the thumb added.

Press return when you are done.

→

The word 'the' is very common. It can be easily made by pressing the first 3 fingers in order: index, then middle, then ring.

Type the word: the

→

***** The Basic Chords *****

In this section you will be introduced to the basic chords and how to use them to make lower case letters.

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→

Now type full stop (period) and comma. Note that the comma is the same chord as the full stop, with the thumb added.

Press return when you are done.

→

The word 'the' is very common. It can be easily made by pressing the first 3 fingers in order: index, then middle, then ring.

Type the word: the

→

Experimenter: Use this (*point to 2nd paper*) for this part of the tutorial.

There are several chords that form the fingers into similar shapes to the letters they represent. Some of these chords are based on sign language. Use the chord shape list you were given as a reference. Type the following letters a few times each and press return:

c shaped like c

→

f shaped like F

→

i shaped like i, as in sign language

→

l all the fingers are in a line, they're shaped like l

→

m shaped like m

→

n shaped like n

→

r shaped like r

→

y shaped like y, as in sign language

→

Now type the sentence:

let their chimney fly. (Don't forget the full stop!)

→

Referring to the chord list, type the letter s

→

Now type the sentences:

this is it.

→

let their chimney fly.

→

Type the letters a and d:

→

Now type:

and

→

this and that

→

let their chimney fly.

→

this is it.

→

Type the letter g

→

Now type:

ing

→

Note that 'ng' is formed by the first two fingers(index and middle)
followed by the second two fingers (middle and ring).

Type again: ing

→

Now type:

thing

→

this and that thing

→

let their chimney fly.

→

The letters o, b, and p, are formed using similar chords.

Type three times: obp

→

Now type:

bop

→

this and that thing

→

let their chimney fly.

→

bop

→

Experimenter: Use this (*point to 2nd paper*) for the next part of the tutorial.

There are three letters similar to the letter u:

u, w, and v.

The chords for these letters are also similar. Also note that the chord for u is shaped like a U made of the index and little fingers.

Using the chord shape list as a reference, type a few times each:

u

→

w (like u + the thumb)

→

v (like u + the ring finger)

→

four wives

→

vipers usually wobble.

→

this and that thing

→

let their chimney fly.

→

four wives

→

Now type the letters x, z, k, j, and q, three times each.

Note that z is just s + the little finger.

also note: q is u plus the middle finger.

→

Type:

six joke quizzes

→

vipers usually wobble.

→

this and that thing

→

let their chimney fly.

→

four wives bop.

→

the quick brown fox jumps over the lazy dog.

→

Congratulations! You are now over the hard part.
Rest for a moment, then press return to continue.

→

***** The Shift Modes *****

In the last section you learned all of the basic chords and characters that are listed in the first and second columns of the chord list. Now you will learn about the next three columns: caps (upper case), number, and punctuation modes.

There are two shift keys: caps and number.
Pressing a shift key once turns it on for the next one character typed.
Pressing it twice rapidly, locks it on for all characters typed.
When the shift is on, pressing it once turns it off.

The third column in the chord list shows which characters will be generated by each chord when caps is on.

Press return to continue.

→

***** The Caps Mode *****

Press the caps key once. A green light should turn on next to it. You have now set the caps mode. The next one character you type will be capitalised.

Type the sentence:
Let Their Chimney Fly.

→

Press the caps twice in rapid succession. A red light should turn on. This means that caps are locked.

Type the sentence:

THIS AND THAT THING

→

To exit the caps mode, press the caps key once. Note that light turns off when you exit the mode.

Important: Return, space and backspace are unaffected by the shift keys. If the shift key is pressed once, it will stay on until a key other than return, space, and backspace are pressed. Also, the full stop and comma are unchanged by the caps key.

Press return to continue.

→

***** The Number Mode *****

The number key works in the same way as the caps key.
The fourth column in the chord list shows the characters generated by the chords when the number key is on.
(note that the full stop and comma are unchanged by the number mode)

Double press the number key to lock on the number mode.

The numbers 1-4 are made in this mode by using the first four fingers.
Type the following numbers five times each:

1 (index finger)

→

2 (middle finger)

→

3 (ring finger)

→

4 (little finger)

→

The numbers 5-8 are just the first four fingers, plus the thumb.

Type the follwing numbers five times each:

5 (index finger + thumb)

→

6 (middle finger + thumb)

→

7 (ring finger + thumb)

→

8 (little finger + thumb)

→

Type the following numbers five times each:

9 (index finger + middle + thumb)

→

0 (index finger + middle + ring + thumb)

→

Type:

1 2 3 4 5 6 7 8 9 10

→

The number mode also contains mathematical symbols. Some of them are based on letters. These can be used as mnemonic devices.

Type the following five times each:

+ P for Plus

→

- M for Minus

→

* X for multiply or B for By.

→

/ D for Division

→

= L for equal

→

^ K for Karat

→

Type:

$2.7 + 9,000/45 - 2^6 = 138.7$

→

Parentheses are made in the number mode by:

(first two fingers (index and middle)

→

) second two fingers (middle and ring)

→

Square brackets are made by:

[(index and little fingers)

→

] [+ thumb (index and little + thumb)

→

type:

$()()()()[] [] [] []$

→

Turn off number mode by pressing the number key once, and rest for a moment.

Press return to continue.

→

The Punctuation Mode

Punctuation mode is made by having both the caps and number modes on at the same time.

Double press caps. Now double press number.

Note: they can be pressed in either order.

Full stop and comma can NOT be made in this mode. The full stop becomes colon and comma becomes semicolon. Return, space and backspace remain unaffected.

Type colon and semicolon:

→

Experimenter: Use this (*point to 2nd paper*) for the next two characters.

There are three quote characters: ' (the apostrophe, single quote, or close quote), " (double quote), and ` (backwards quote or open quote).

Using the chord shape list as a reference, type the following:

' (index finger)

→

" (index + middle)

→

` (index + middle + thumb)

→

The rest of the punctuation chords in this mode correspond to letters. Again, this can be used mnemonically.

Type the following five times each:

! E for Exclamation point

→

\$ S for dollar sign

→

P for Pound sign

→

< L for Less than

→

> G for Greater than

→

& A for And

→

| O for Or (as in the c programming language)

→

% C for perCent

→

? I for Inquiry or Q for Question

→

~ Y for wiggly

→

@ H for Hat - (Hat rhymes with 'at')

→

There are also punctuation chords based on the number chords:

For example, both * and ^ are the same chords in both punctuation and number modes.

Type the following five times each:

* X for multiply or B for By.

→

^ K for Karat

→

{ like [

→

} like]

→

_ like - (Minus)

→

\ like / (Division)

→

Turn off punctuation mode by pressing the caps and number keys once.

Press return to continue.

→

***** Review *****

Type the following:

I said, "Hello world! I have 16 oranges."

→

six joke quizzes

→

Vipers usually wobble.

→

this and that thing

→

$2.7 + 9,000/45 - 2^6 = 138.7$

→

Let their chimney fly.

→

Four wives bop.

→

The Quick Brown Fox Jumps Over The Lazy Dog!

→

```
*****      Congratulations! You are finished!      *****
```

```
→
```

```
→
```

The experimenter presses <Escape> on the keyboard to exit the tutorial.

D.3 The Chording Sessions

The chording sessions consisted of text entry trial and data entry trials. The text entry trials used the text from the book *Alice's Adventures in Wonderland*. One subject managed to get as far as the third paragraph of Chapter Three (399 lines).

The data entry text was mostly tabular stock market data. The intent was to use characters in the Number mode, with occasional switching to punctuation and text. The furthest any subject achieved was 158 lines. The first 158 lines of the data entry text follows:

162.31	+3.15	159.55	162.32	159.55
471.23	+4.12	467.48	471.48	467.48
399.51	+3.66	396.00	399.80	396.00
448.62	+0.58	448.04	449.13	448.00
263.98	-0.69	264.63	264.89	263.76
94.32	-0.31	94.32	94.32	94.32
99.13	-0.25	99.13	99.13	99.13
89.51	-0.12	89.51	89.51	89.51
1277.22	+8.87	1267.78	1278.72	1267.78
3829.73	+28.26	3798.10	3833.43	3798.10
1484.84	+12.58	1472.03	1486.24	1472.03
177.30	+0.59	176.84	177.76	176.71
710.24	+0.46	709.64	711.02	708.50
768.18	+6.06	763.61	768.18	762.12

890.14	+0.42	890.20	890.47	888.59
777.24	+4.14	773.69	777.30	773.69
901.92	-3.86	906.40	906.52	900.53
681.00	-0.17	681.73	682.72	678.96
342.05	+2.84	339.90	342.05	339.21
719.47	-0.67	720.14	721.38	718.79
254.79	+1.54	253.25	254.94	253.25
200.51	+0.95	199.56	200.60	199.56
322.81	+2.19	320.62	322.97	320.62
227.08	+0.09	226.99	227.61	226.67
200.13	+1.17	198.96	200.26	198.96
433.54	+3.07	430.52	433.97	430.52
465.94	+3.59	462.32	466.30	462.32
250.39	+1.01	249.58	250.39	249.57
282.20	+1.06	281.17	282.21	281.17
2089.29	+10.94	2086.75	2094.30	2086.75
9378.92	+11.07	9363.44	9397.42	9334.89
3095.3	+19.4	3076.9	3095.3	3069.5
2486.640	-40.350	526.990	2540.380	2484.900
1941.08	-7.27	1940.27	1946.64	1927.64
2326.94	+4.35	2322.59	2333.31	2322.59
1926.5	+0.0	1926.5	1926.5	1926.5
19261.45	-22.91	19246.45	19298.96	19115.72
1705.15	-3.45	1709.90	1714.41	1705.15

1	4,659,300	31 1/4	- 1/8
2	3,258,600	48 7/8	+2 7/8
3	2,978,900	52 1/4	-1 1/4
4	2,901,200	23 1/2	- 1/8
5	1,928,700	62 1/2	+1
6	1,908,900	29	+ 1/2
7	1,850,100	20 3/8	- 1/4
8	1,833,300	15 5/8	- 1/2
9	1,809,200	38 3/4	+ 1/8
10	1,782,200	16 1/4	0
11	6,173,800	33 3/4	+ 3/4
12	3,872,300	69 1/4	+7 7/8
13	3,678,800	46 5/16	-2 1/16

14	3,045,100	64 1/2	+2 1/4
15	2,861,900	74 1/4	+2 3/4
16	2,347,400	62 1/4	+1 5/8
17	2,297,500	23 1/8	+ 3/8
18	2,213,800	22 1/8	+ 1/2
19	1,868,800	44 1/8	+1
20	1,336,400	39 5/8	+ 3/4
21	667,900	33	+1 3/4
22	481,100	8 3/8	+1 3/8
23	437,700	33 1/4	+ 3/4
24	427,800	4 1/16	+ 9/16
25	422,000	8 7/8	+ 1/4
26	344,400	8	+ 1/8
27	287,500	40 3/4	+ 3/4
28	252,700	20 5/8	+3 1/4
29	1,858,800	26 5/16	- 5/16
30	250,300	3 7/8	- 3/16

London Gold	\$385.10	-0.15	385.25
New York Gold	\$384.50	-0.5	385.00
Fed Funds Rate	\$5.75	+0.875	4.875
UST 3m Bill Rate	\$5.27	+0.03	5.24
UST 6m Bill Rate	\$5.69	-0.02	5.71
UST 1y Bill Rate	\$6.11	+0.08	6.03
UST 3y Note % Yield	\$7.36	-0.05	7.41
UST 5y Note % Yield	\$7.65	-0.05	7.70
UST 10y Note % Yield	\$7.93	-0.06	7.99
UST 30y Bond % Yield	\$8.08	-0.07	8.15

4.500	4.125	4.375	808	+58%	+0.125	(+3)
17.375	16.875	17.125	4379	+56%	-0.125	(-1)
24.750	24.250	24.375	1365	+133%	-0.375	(-2)
31.625	31.250	31.250	55511	+215%	-0.125	(-0)
27.875	27.250	27.875	3132	+63%	+0.500	(+2)
10.375	9.875	10.125	8254	+78%	+0.125	(+1)
60.250	59.250	60.000	14542	+72%	+1.000	(+2)
5.250	4.875	5.000	419	+56%	-0.125	(-2)
43.875	42.875	43.875	3167	+64%	+1.000	(+2)

13.125	12.625	12.875	749	+109%	-0.250	(-2)
6.625	6.250	6.625	4054	+116%	+0.375	(+6)
48.750	47.375	48.750	38735	+86%	+2.750	(+6)
39.125	38.750	38.750	7346	+177%	-0.625	(-2)
9.875	9.000	9.625	2347	+220%	+0.250	(+3)
12.750	12.375	12.500	514	+147%	-0.125	(-1)
31.250	30.750	31.250	18245	+56%	+0.500	(+2)
38.375	38.000	38.000	6532	+66%	-0.500	(-1)
8.375	8.125	8.250	3921	+653%	+0.000	(+0)
16.250	15.625	15.625	21744	+73%	-0.500	(-3)
9.125	8.875	9.125	475	+303%	+0.250	(+3)
60.125	58.000	59.500	3527	+55%	+1.500	(+3)
30.500	30.000	30.250	1188	+101%	+0.375	(+1)
23.750	23.000	23.250	9514	+64%	+0.000	(+0)
23.250	23.000	23.125	646	+873%	+0.250	(+1)
29.375	28.875	29.250	11287	+56%	+0.000	(+0)
30.125	29.750	30.000	2273	+106%	+0.250	(+1)
57.375	56.125	57.250	7054	+69%	+0.375	(+1)
38.000	37.000	37.375	5831	+87%	-0.750	(-2)
50.875	49.875	50.750	3467	+63%	+1.250	(+3)
51.875	51.375	51.750	10027	+60%	-0.062	(-0)

exa	E	10 ¹⁸	10 ³⁶	10 ⁵⁴
peta	P	10 ¹⁵	10 ³⁰	10 ⁴⁵
tera	T	10 ¹²	10 ²⁴	10 ³⁶
giga	G	10 ⁹	10 ¹⁸	10 ²⁷
mega	M	10 ⁶	10 ¹²	10 ¹⁸
hectokilo	hk	10 ⁵	10 ¹⁰	10 ¹⁵
myria	ma	10 ⁴	10 ⁸	10 ¹²
kilo	k	10 ³	10 ⁶	10 ⁹
hecto	h	10 ²	10 ⁴	10 ⁶
basic unit	-	1 meter, 1 gram, 1 liter	1 meter ²	1 meter ³
deci	d	10 ⁻¹	10 ⁻²	10 ⁻³
centi	c	10 ⁻²	10 ⁻⁴	10 ⁻⁶
milli	m	10 ⁻³	10 ⁻⁶	10 ⁻⁹
decimilli	dm	10 ⁻⁴	10 ⁻⁸	10 ⁻¹²

centimilli	cm	10 ⁻⁵	10 ⁻¹⁰	10 ⁻¹⁵
micro	u	10 ⁻⁶	10 ⁻¹²	10 ⁻¹⁸
nano	n	10 ⁻⁹	10 ⁻¹⁸	10 ⁻²⁷
pico	p	10 ⁻¹²	10 ⁻²⁴	10 ⁻³⁶
femto	f	10 ⁻¹⁵	10 ⁻³⁰	10 ⁻⁴⁵
atto	a	10 ⁻¹⁸	10 ⁻³⁶	10 ⁻⁵⁴

28.750	28.500	28.750	5985	+99%	+0.250	(+1)
34.875	33.250	34.875	2916	+68%	+1.625	(+5)
33.625	33.250	33.500	2913	+82%	-0.125	(-0)
5.875	5.500	5.875	529	+55%	+0.250	(+4)
46.750	44.625	46.750	1761	+55%	+2.375	(+5)
8.250	7.750	8.000	4987	+160%	+0.125	(+2)
46.875	44.875	45.250	15515	+175%	-1.500	(-3)
59.250	58.750	59.000	8571	+138%	-0.500	(-1)
2.625	2.375	2.500	1902	+153%	-0.125	(-5)
56.250	55.500	56.250	1279	+44%	+0.750	(+1)
51.375	50.625	51.250	12806	-15%	+0.875	(+2)
74.500	73.875	74.125	6323	+27%	+0.375	(+1)
1.812	1.500	1.688	2264	+13%	+0.125	(+8)
22.375	21.875	22.125	522	+46%	-0.250	(-1)
29.375	28.875	29.250	11287	+56%	+0.000	(+0)
41.375	39.500	40.250	468	+180%	-0.500	(-1)
31.625	30.625	31.250	9569	+87%	-0.125	(-0)
31.750	30.750	31.250	2501	+605%	+0.000	(+0)
19.625	19.500	19.625	101	+111%	+0.000	(+0)
10.500	10.000	10.500	288	+90%	+0.062	(+1)
35.000	34.250	34.375	2141	+259%	-1.625	(-5)
8.000	7.250	7.562	696	+58%	-0.438	(-5)
10.750	10.375	10.500	255	+132%	-0.250	(-2)

Appendix E

Calculating the Effective Width for Fitt's Law

Fitts' law requires W to be a one-dimensional term. In the performance experiments, W needed to be derived from a two-dimensional button. It was decided to use a method described by MacKenzie (MacKenzie, 1992) which the span of the rectangle across the direction of the approach vector is used.

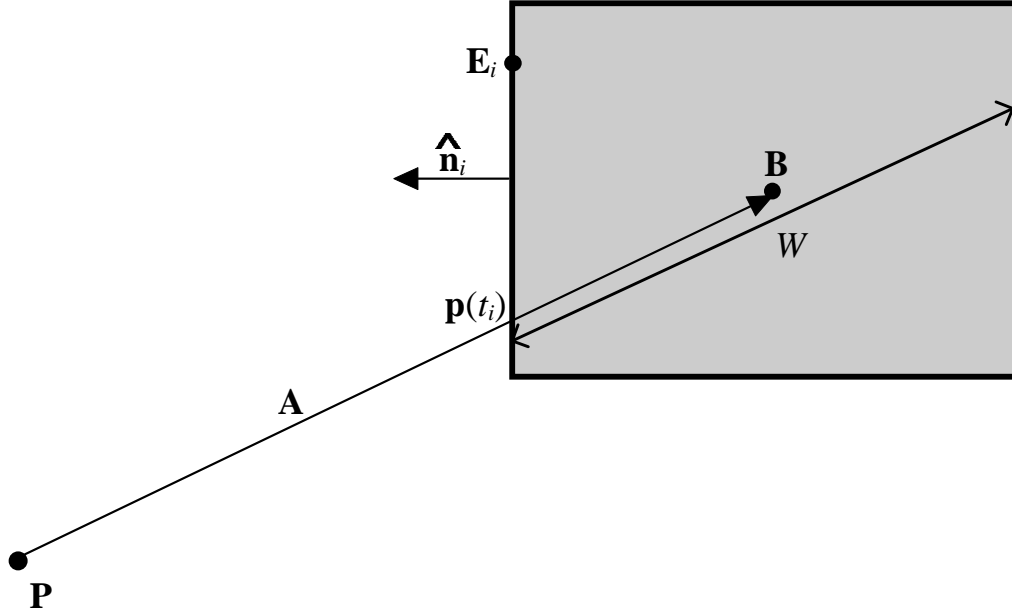


Figure E.1: The button and the approach vector

The position of the pointer at the start of the task is point P . The centre of the button is point B . The approach vector A is defined as:

$$A = B - P \quad (E.1)$$

The point p is the point where the vector A intersects the rectangle. The point p can be found by using the Cyrus-Beck clipping algorithm (Foley et al., 1990), which is described as follows:

p is a function of the parameter t such that:

$$p(t) = P + tA. \quad (E.2)$$

E_i is any arbitrary point on edge i and \hat{n}_i is the outward normal vector for that edge. This yields:

$$\hat{n}_i \cdot (p(t_i) - E_i) = 0 \quad (E.3)$$

where t_i is the value of the parameter t where it intersects edge i . This can be solved for t_i by:

$$\hat{n}_i \cdot (P + t_i A - E_i) = 0 \quad (E.4)$$

$$\hat{n}_i \cdot (E_i - P) = \hat{n}_i \cdot t_i A \quad (E.5)$$

and finally,

$$t_i = \frac{\hat{n}_i \cdot (E_i - P)}{\hat{n}_i \cdot A} \quad (E.6)$$

p is then chosen from the smallest defined value of t_i between 0 and 1, yielding:

$$W = 2|B - p| \quad (E.7)$$

Appendix F

Deriving the Neural Network

The neural network used in the Biofeedback Pointer is simple perceptron which uses the EMG spectra as input, and outputs a two-dimensional position vector. In this appendix we will show the derivation of the equations used to calculate the weights for the neural network.

F.1 Definitions

The input data \mathbf{S} is a set of N frequency spectra

$$\mathbf{S} = (\mathbf{s}_0 \dots \mathbf{s}_{N-1}) \quad (\text{F.1})$$

Each frequency spectrum is an array consisting of B bins.

$$\mathbf{s}_i = (s_{i,0} \dots s_{i,B-1}) \quad (\text{F.2})$$

In order facilitate manipulation of the data, it can be converted to the linear array \mathbf{a} of $N + B + 1$ points so that

$$\mathbf{a} = (1, s_{0,0} \dots s_{0,B-1}, s_{1,0} \dots s_{i,j} \dots s_{N-1,B-1}) \quad (\text{F.3})$$

The leading 1 in \mathbf{a} is to allow for an offset value for the weights.

There is a set of test points (\mathbf{x}, \mathbf{y}) where (x_i, y_i) is the i th test point associated with the i th input data \mathbf{a}_i . There is a set of weights \mathbf{w}_x and \mathbf{w}_y which, when applied to each \mathbf{a}_i yield a set of points (x'_i, y'_i) which are as close as possible to original points. In other words:

$$x_i \approx x'_i = \mathbf{w}_x^T \mathbf{a}_i \quad \text{or} \quad \mathbf{x} \approx \mathbf{x}' = \mathbf{w}_x^T \mathbf{a} \quad (\text{F.4})$$

$$y_i \approx y'_i = \mathbf{w}_y^T \mathbf{a}_i \quad \text{or} \quad \mathbf{y} \approx \mathbf{y}' = \mathbf{w}_y^T \mathbf{a} \quad (\text{F.5})$$

where \mathbf{a} is the matrix generated from all \mathbf{a}_i .

The errors ϵ_x and ϵ_y are defined by

$$\epsilon_x = \mathbf{x} - \mathbf{x}' \quad (\text{F.6})$$

$$\epsilon_y = \mathbf{y} - \mathbf{y}' \quad (\text{F.7})$$

In order to find the best value for the weights we want to minimise the errors. We can solve exactly for the weights which minimise the errors by a method very similar to a linear least squares fit.

F.2 Derivation

Since the equations for the error are equivalent and independent, we can examine the x case to derive both equations. Dropping the x subscripts for now, we find the error squared is:

$$\epsilon^2 = (\mathbf{x} - \mathbf{x}')^2 \quad (\text{F.8})$$

$$= (\mathbf{x} - \mathbf{w}^T \mathbf{a})^2 \quad (\text{F.9})$$

$$= x^2 + \mathbf{w}^T (\mathbf{a} \mathbf{a}^T) \mathbf{w} - 2(\mathbf{x} \mathbf{a}^T) \mathbf{w} \quad (\text{F.10})$$

We then define $\mathbf{R} = \mathbf{a}\mathbf{a}^\top$ and $\mathbf{q} = \mathbf{x}\mathbf{a}^\top$. Note that \mathbf{R} is independent of x . Replacing the terms in the Equation F.10 we get:

$$\epsilon^2 = x^2 + \mathbf{w}^\top \mathbf{R} \mathbf{w} - 2\mathbf{q} \mathbf{w} = g(\mathbf{w}) \quad (\text{F.11})$$

Where g is a function of \mathbf{w} which we need to minimise to find the best values for \mathbf{w} . This is done by:

$$\sum_{i=0}^{N+B} \frac{\partial g(w_i)}{\partial w_i} = 2\mathbf{R} \mathbf{w} - 2\mathbf{q} \quad (\text{F.12})$$

We define the \mathbf{w}^* as the array which makes Equation F.12 equal to zero.

$$2\mathbf{R} \mathbf{w}^* - 2\mathbf{q} = 0 \quad (\text{F.13})$$

$$\mathbf{R} \mathbf{w}^* = \mathbf{q} \quad (\text{F.14})$$

$$\mathbf{w}^* = \mathbf{R}^{-1} \mathbf{q} \quad (\text{F.15})$$

Which for both x and y becomes:

$$\mathbf{w}_x^* = \mathbf{R}^{-1} \mathbf{q}_x \quad (\text{F.16})$$

$$\mathbf{w}_y^* = \mathbf{R}^{-1} \mathbf{q}_y \quad (\text{F.17})$$

Solving these equations is easily done by well established methods. The Singular Value Decomposition method described in Press et al. (1992) was used for the Biofeedback Pointer.

Appendix G

Technical Specifications for the Biofeedback Pointer

G.1 The Physiological Amplifiers

The four physiological amplifiers are custom-made and designed specifically for reading the EMG. Each one contains the amplification hardware (see Section 3.3.3) and is encased in a hard epoxy resin, approximately 4.5cm long and 1.5cm wide. On the bottom side of each physiological amplifier are two connectors spaced 2.54cm apart. The specifications for these amplifiers are detailed in Table G.1.

Table G.1: Physiological Amplifier specifications

Input Impedance	10G Ω
Input Offset Limit	$\pm 350\text{mV}$
Overall Gain	$\times 1000$
Noise	5 μV p-p
Frequency Response	16Hz - 1.6kHz
Common Mode Rejection	> 100dB
Current Protection Limit	< 500 μA
Supply Voltage	$\pm 4.5\text{V}$
Amplifier Current	3mA

G.2 The Analogue-Digital Converter

The analogue-digital converter used was a Pico ADC-11 (Pico Technology LTD, n.d.). The specifications are described in Table G.2 and the pin connections to the EMG amplifier are described in Table G.3.

Table G.2: Specifications for the Pico ADC-11

Resolution	10 bits
Number of input channels	11
Input voltage range	0–2.5V
Maximum sampling rate	max 18k samples per second
Repeatability	± 1 at 25°C
Input overvoltage protection	± 30 V
Input impedance	$> 1\text{M}\Omega$
Digital output voltage	typically 3–5V, depending on computer and load
Digital output impedance	approx. 1–2k Ω depending on type of computer
Input collector	25 way female D-type
Output collector	25 way male D-type (connects to PC printer port)

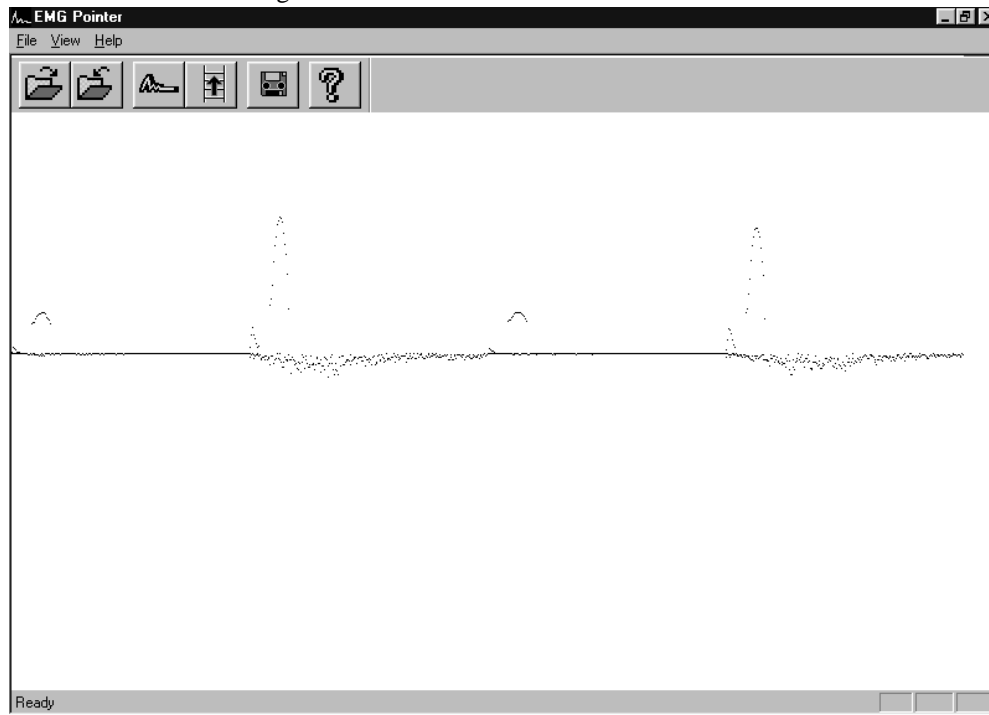
Table G.3: Output pin connections for the ADC-11

Pin	Function	Use
1	Digital output / voltage output	unused
2	Signal ground	ground
3	Analogue input channel 1	EMG 1
4	Analogue input channel 2	EMG 2
5	Analogue input channel 3	EMG 3
6	Analogue input channel 4	EMG 4
7	Analogue input channel 5	unused
8	Analogue input channel 6	
9	Analogue input channel 7	
10	Analogue input channel 8	
11	Analogue input channel 9	
12	Analogue input channel 10	
13	Analogue input channel 11	
14–25	Unused	

Appendix H

The Biofeedback Pointer Software

Figure H.1: The Biofeedback Pointer Software



H.1 Introduction

The windows application “EMG Pointer” was written to provide an easy to use graphic interface to the Biofeedback Pointer. The primary use of the application is to read the Analogue/Digital converter (ADC) and convert the data into pointer motion. In addition the application can train the neural network, run the performance test experiment, and perform several diagnostic functions.

The application is a 32 bit Windows 95 application written in Microsoft Visual C++ on a Pentium 133MHz desktop computer.

H.2 Using the Application

The application is operated by either buttons, pull-down menus, or hotkeys. Information is either displayed in the main window, status bar, a pop-up window, or saved to disk as a binary data file.

H.2.1 Button control

There are two sets of buttons which control the application. The first is the standard Windows 95 set of window control buttons. The upper right corner contains buttons which iconify, maximise and close the application. The upper left corner contain the application’s icon which is designed to resemble the frequency spectrum of an EMG. Pressing it will display a pull-down list of standard window control operations. The second set of buttons control software specific functions and are detailed here.



Retrieve a saved neural network file The weights of the neural network can be saved as a binary file, for analysis or to be used later. This button reads the file `data.nnt` and stores the weights in a new neural network. If the EMG data is being read, the pointer control will start immediately.



Save a neural network in a file This saves the weights of the neural network in a file called `data.nnt`.



Start or stop reading EMG data This starts or stops the application reading the ADC on the parallel port (Section H.3). The data will be displayed in the main window (Section H.2.4).

If the pointer has been trained, or the neural net retrieved from a file, the application will take immediate control over the pointer. When pressed again the application will stop controlling the pointer.

Note that the mouse still works when the application has control of the pointer. In this case, either device can be used to control the pointer.



Train the neural network When this is pressed, the neural network training will start immediately. The pointer moves to the centre of the screen and performs several motion which the user must follow (see Section 3.3.4 for exact details). After the data is collected the programme pauses a short time while the neural network is calculated (Appendix F). The network is calculated eight times, with time delays ranging from zero to 448ms. The weights with the least error are used in the neural network. Pointer control begins immediately upon termination of the calculations. It is possible that some the matrixes are unsolvable. If this occurs, no network is generated, and no pointer control occurs. The network must be trained again. In practice this is an extremely rare occurrence, but it can happen. If this button is pressed again while training, the training stops immediately without calculating the network.



Start/stop recording EMGs When pressed, this causes all EMGs to be saved in the file `emg.dat` until the button is pressed again. Every 64ms, the 4 reduced spectra of 8 points are saved. This is a diagnostic tool for saving data to be analysed by external programmes.



Display application information This pops up a window displaying the application's name, author and copyright information.

H.2.2 Menus

There are three pull-down menus which can be used to control the application.

File	Exit	— Exits the application
View	Toolbar	— Hides or displays the buttons.
	Statusbar	— Hides or displays the status bar at the bottom on the window.
	Start/End measurements	— Starts or stops reading the EMG data, as above.
	Train Pointer	— Trains the pointer as described above.
	Performance Test	— Starts the performance test which is described in Section 5.2.3. There is no button which performs this function. this is to avoid problem with subjects accidentally pressing it during an experiment.
Help	About EMG Pointer	— Pops up the information window as above.

H.2.3 Hotkeys

There are three hotkeys used by the application. Hotkeys are necessary since the application takes control over the pointer, and there must be a way to operate the commands with just keyboard commands.

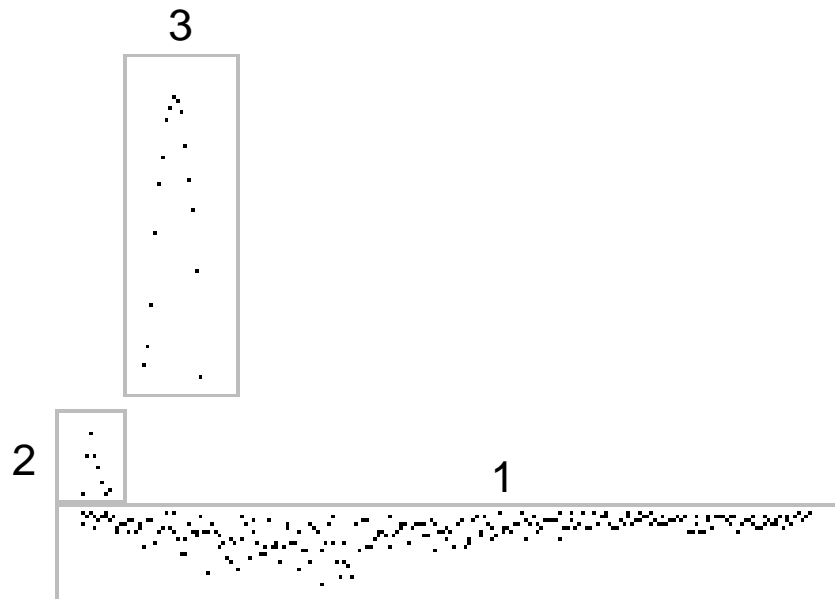
<Control>-P Start the performance test

<Control>-S Start / Stop reading EMG data

<Control>-T Start /Stop training

H.2.4 Main Display Area

Figure H.2: The real-time displayed plot for one EMG signal



The display contains the output of all four EMG amplifiers. Each of the signals is displayed in three ways, as shown in Figure H.2. These are all used for diagnostic purposes, and have no effect on the running of the application. These are displayed primarily to let the operator know if anything has gone wrong. Problems such as broken equipment, loose electrodes, weak batteries, and the like are fairly evident just by observing the display.

The first graph is a plot of the entire power spectrum. This is generated by the square of the absolute value of the fast fourier transform (FFT) of the EMG signal. This is displayed downward so as to not interfere with the other two graphs. This is used to determine the strength of the signal, which is especially useful when attaching the electrodes.

The second graph is the spectrum, rebinned down to 8 points. These are the values fed into the neural network.

The third graph is a plot of the integral of the spectrum over time. The 16 values correspond to the last 1.024 seconds. This plot shows that the wrist was recently extended and then relaxed. The horizontal and vertical offset is to enable the plot to be clearly differentiated from the others.

H.2.5 Status Bar

The status bar displays the current state of the application to the user. In the lower right it displays the shift states of the device (this has no effect on the application). The lower left displays text information to the user such as the purpose of a button or comments like “Pointer training will start immediately”.

H.3 Internal Processes

When the EMG reading is started, a regular timer event is registered. This tells the window manager to call the `TimeProc` function every millisecond. This function reads the ADC and stores the value in an array. In addition, every 64th call, a copy is made of the entire array, and a message is sent to the operating system to tell it to update the pointer. Updating is done in a separate procedure with a copy of the raw data to allow the millisecond timing to run in parallel without any interference.

When the window manager receives the message to update the pointer it calls the `showData` function. This function calculates the square of the absolute value of the complex FFT of the data. The DC components of the power spectra are removed to avoid problems with signal drift. The spectra are then rebinned down to 8 points each. The full spectra, rebinned spectra, and the sum over each spectrum are then displayed in the main window.

If the pointer is being trained, the position and the 4 reduced spectra are saved for later calculations. If the pointer has been trained successfully, the 4 reduced spectra are fed into the neural network to receive the raw (x, y) position. This value is scaled by Equation 3.9 and added to the current position of the pointer.

This process is repeated until the data reading is turned off.

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