Stroke Feedback System
Final Design Report

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Stroke and Hemiparesis

- Hemiparesis – weakening of or inability to use one side of body
- Caused by lesions in primary motor cortices
- Can cause major fine motor deficiencies, leading to a decrease in quality of life

Stroke Rehabilitation: Neurophysiological Hypothesis

- Hypothesis that brain shuts down ineffective motor pathways (Liepert 2000)
- Need device to provide feedback in response to activation of successful motor neuron pathway
- Hypothesis that multi-modal feedback is key for recognition of successful pathways
- Piron, et al. have shown that augmented-feedback rehab facilitates motor recovery

Project Need

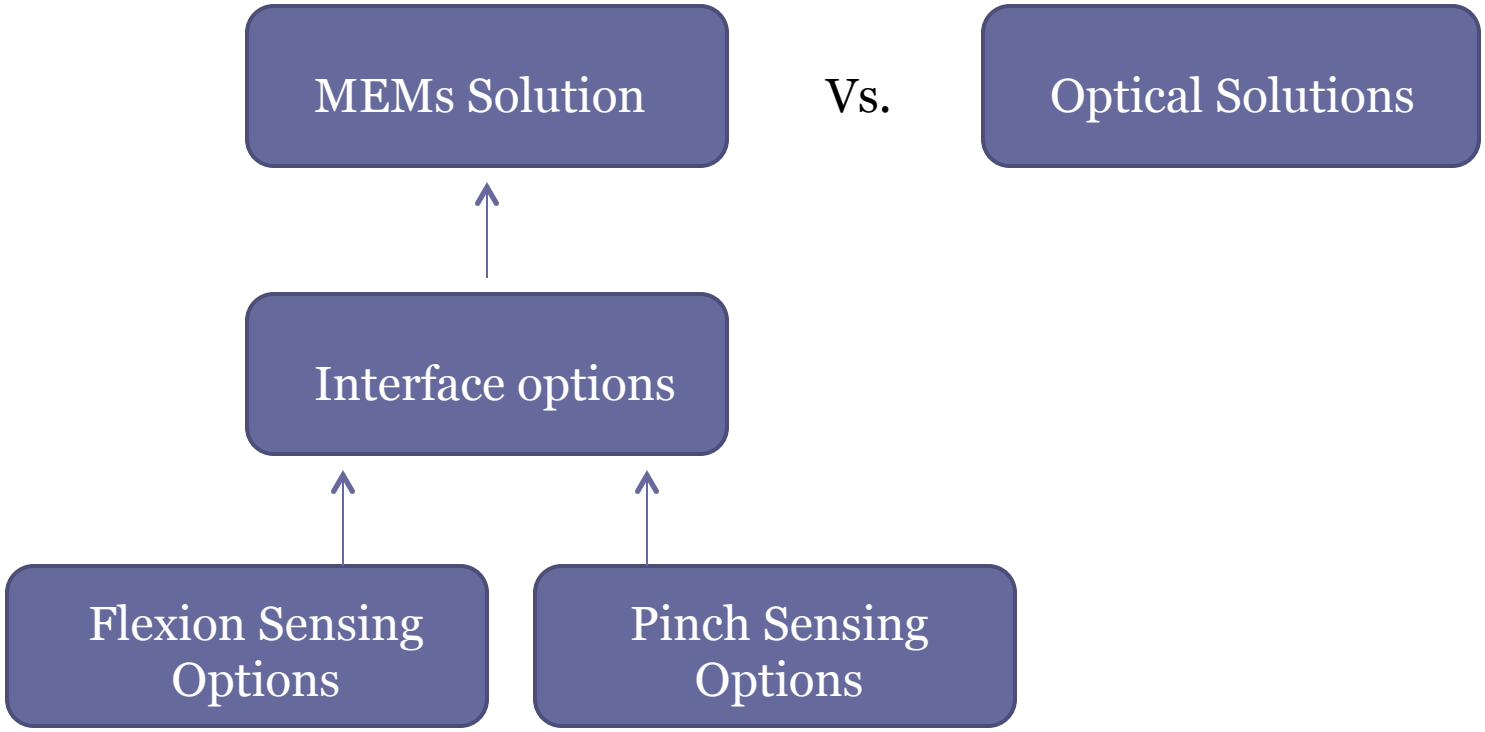
- Feedback amplifier for use in proof-of-concept experiments to test effectiveness of multimodal feedback
- Focus on fine finger movement (finger flexion and pinching movement)

Design Specifications

- System Specifications
  - Sampling rate: 100 Hz
  - System must not harm patient
  - Powered by wall outlet, computer, or battery pack
  - User must be able to set operation mode
- Design Specifications
  - Weight on hand: <200 g
  - Total weight: <5 kg
  - Must fit middle 90% of both genders, as defined by ANSUR
  - Must not severely limit hand motion
- Feedback Specifications
  - At least 2 forms (auditory, tactile, visual)
  - Must be detectable by the user, but not damaging

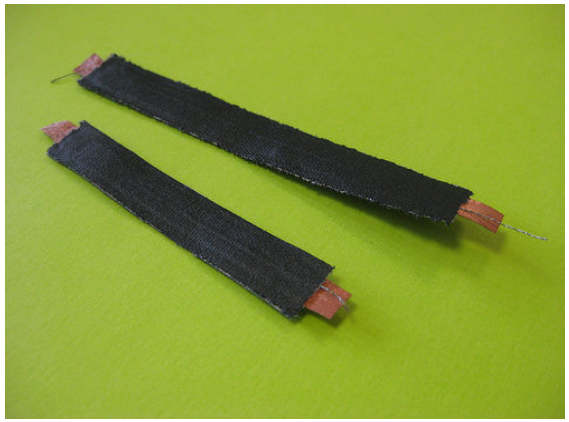
Design Selection

- Bottom-up design approach to microelectromechanical system



Pressure Sensitive Conductive Material

- Velostat/Linqstat
- Conductive material whose resistance varies with pressure applied
- Positioned similarly to flex sensing resistor
- Main drawback
  - Must be manufactured into a sensor

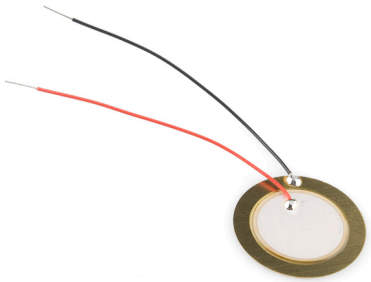


http://www.adafruit.com/products/1361 ;

Pinch Sensor Comparison

Piezoelectic Sensor

- Produces a charge in the material when deformed
- Main drawback
  - Suffers from hysteresis

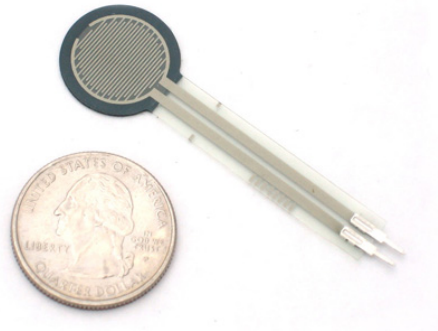


Tactile Switch

- Pinch movement depresses button on switch turning it on
- Main drawback
  - Might be too small

Force Sensing Resistor

- Sensor whose resistance changes when a force is applied
- Main drawback
  - Relatively large compared to fingertip.



Design Change

- We abandoned the tactile switch due to its attachment characteristics
  - Designed to be soldered onto a circuit board
- Use Velostat for pinch sensor as well
  - Coding can turn analog sensor to digital input (essentially)
- Utilizes bulk Velostat – cost effective

MEMs Interface Analysis

	Weight	Glove	Discrete Components
Accessibility	10	1	8
Safety	9	7	8
Sanitation	9	5	7
Customizability	5	2	9
Cost	6	10	8
Weight	8	8	8
Ease of Setup	10	10	7
Ease of part integration	7	5	9
Total		337	423

MEMs vs. Optical

	Weight	MEMS Design	LEAP Motion	3Gearsystems	Microsoft Digits	Ascension trakSTAR	Optitrack	Color Glove
Cost	4	10	7	5	6	2	1	5
Portability	8	10	8	6	7	3	0	6
Spatial Resolution	7	5	10	8	7	9	9	5
Temporal Resolution	5	10	8	4	5	9	8	1
Software Involvement	8	10	6	6	1	4	4	3
Patient Accessibility	9	7	9	10	10	10	8	10
Therapist Accessibility	8	8	10	9	8	5	3	9
Feedback Integration	10	10	8	8	8	8	8	8
Total		512	491	434	396	382	315	374

Circuitry

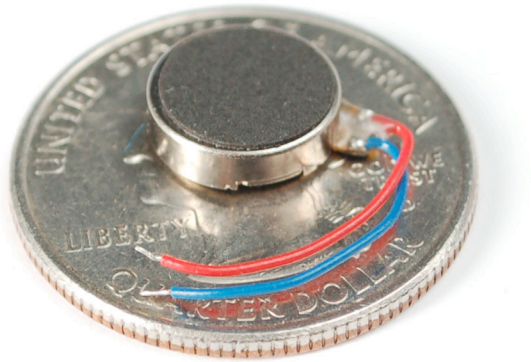
- Large number of inputs and outputs dictated the use of the Arduino Mega 2560
  - 54 digital I/O, 15 PWM outputs, 16 analog ins
- Can sample and convert (analog to digital) at 10 kHz
- Programmable with free software
- Easy to use
- Powered by 7-12 V DC, uses about 100 mA during operation

Feedback Actuators

- Audio:
  - 8Ω, .1W speaker mounts directly to PCB. Driven from Arduino with tone() function.
  - In series with 150Ω resistor the speaker will draw 32 mA max
  - Volume of 80 dB at max power

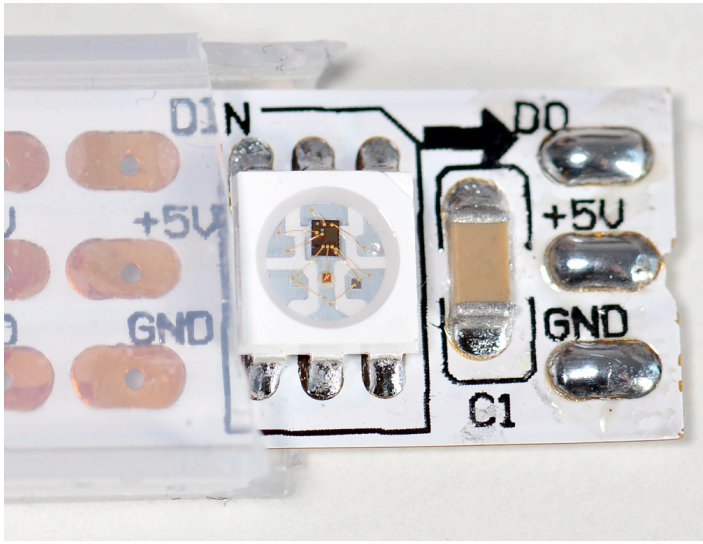
Feedback Actuators

- Tactile:
  - Coin-type vibration motor mounted on finger pad
  - 10mm diameter motor
  - We will limit the strength of the motor by placing it in series with a 50Ω resistor
  - Draws 50mA at 5V



Feedback Actuators

- Visual:
  - Need a small RGB LED that can be integrated onto the hand
  - Adafruit Neopixel Strip – flexible strips of RGB LEDs with built-in driver chip
  - 60 mA max draw at 5V (max voltage)

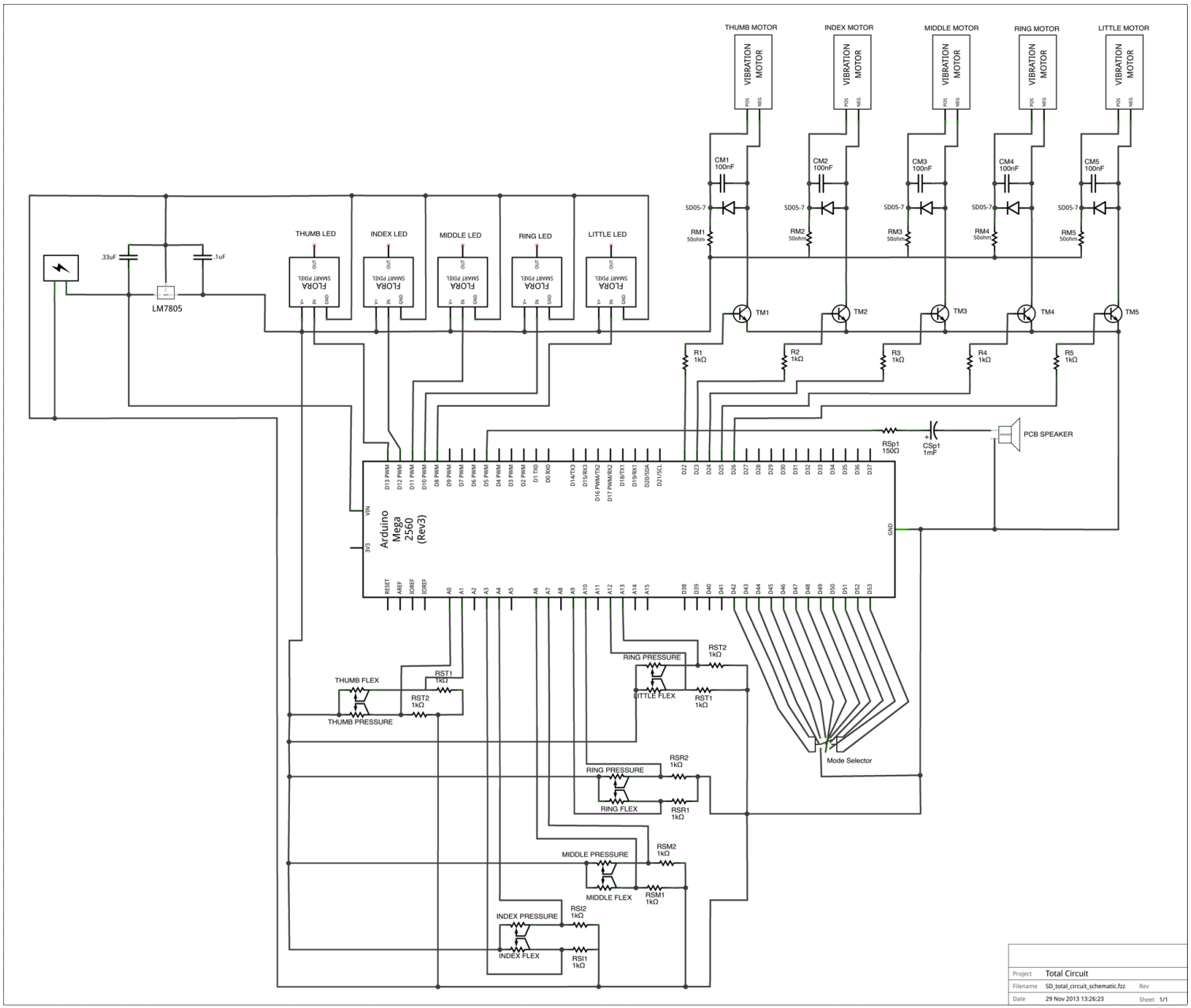


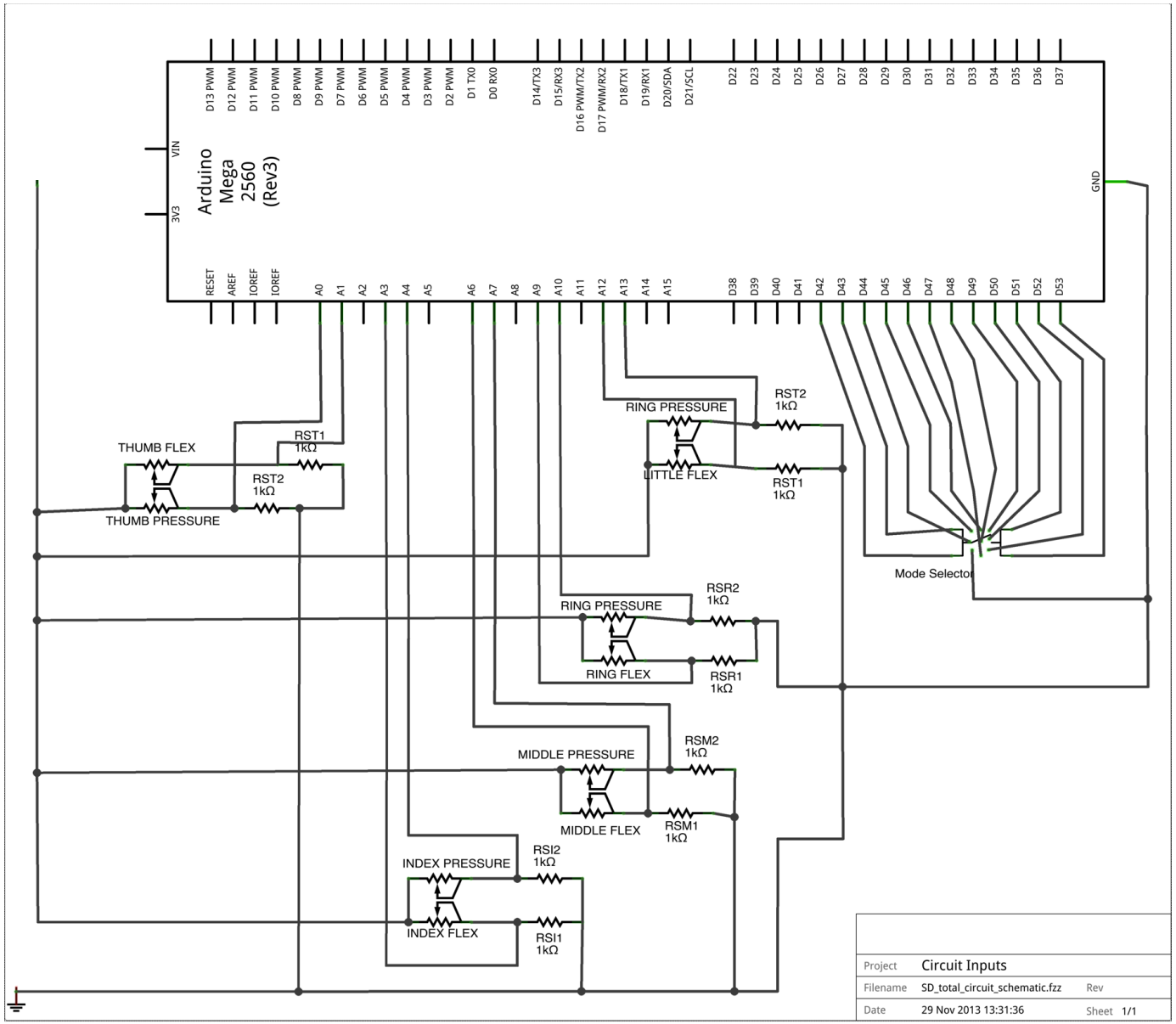
Power Considerations

- How much current will the system draw with everything on?
- Each finger: 60mA + 50mA +5mA +5mA = 120mA
- Speaker: 32mA
- Arduino: ~100mA
- Total: ~732mA, with all components on

PCB Trace Width

- $I = (0.048)(dT^{0.44})(A^{0.725})$ for external traces
  - *dT* is acceptable temp. rise in Celsius, *A* is cross-sectional area (Douglas Brooks, UltraCAD Design, Inc)
- Need at least 12 mil with 10°C allowable rise


THUMB MOTOR
INDEX MOTOR
MIDDLE MOTOR
RING MOTOR
LITTLE MOTOR
VIBRATION MOTOR
POS
NEG
CM1 100nF
CM2 100nF
CM3 100nF
CM4 100nF
CM5 100nF
SD05-7
RM1 50ohm
RM2 50ohm
RM3 50ohm
RM4 50ohm
RM5 50ohm
THUMB LED
INDEX LED
MIDDLE LED
RING LED
LITTLE LED
FLORA SMART PIXEL
OUT
V+
IN
GND
.33uF
.1uF
LM7805
TM1
TM2
TM3
TM4
TM5
R1 1kΩ
R2 1kΩ
R3 1kΩ
R4 1kΩ
R5 1kΩ
RSp1 150Ω
CSp1 1mF
PCB SPEAKER
Arduino Mega 2560 (Rev3)
VIN
3V3
GND
RESET
AREF
IOREF
THUMB FLEX
THUMB PRESSURE
RST1 1kΩ
RST2 1kΩ
RING PRESSURE
LITTLE FLEX
RSR2 1kΩ
RING FLEX
RSR1 1kΩ
MIDDLE PRESSURE
MIDDLE FLEX
RSM2 1kΩ
RSM1 1kΩ
INDEX PRESSURE
INDEX FLEX
RSI2 1kΩ
RSI1 1kΩ
Mode Selector
Project Total Circuit
Filename SD_total_circuit_schematic.fzz
Rev
Date 29 Nov 2013 13:26:23
Sheet 1/1
Made with Fritzing.org


Arduino Mega 2560 (Rev3)
VIN
3V3
GND
D13 PWM
D12 PWM
D11 PWM
D10 PWM
D8 PWM
D9 PWM
D7 PWM
D6 PWM
D5 PWM
D4 PWM
D3 PWM
D2 PWM
D1 TX0
D0 RX0
D14/TX3
D15/RX3
D16 PWM/TX2
D17 PWM/RX2
D18/TX1
D19/RX1
D20/SDA
D21/SCL
D22
D23
D24
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D30
D31
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D33
D34
D35
D36
D37
RESET
AREF
IOREF
IOREF
A0
A1
A2
A3
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A15
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D47
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D49
D50
D51
D52
D53
THUMB FLEX
THUMB PRESSURE
RST1
1kΩ
RST2
1kΩ
RING PRESSURE
LITTLE FLEX
RST2
1kΩ
RST1
1kΩ
Mode Selector
RING PRESSURE
RING FLEX
RSR2
1kΩ
RSR1
1kΩ
MIDDLE PRESSURE
MIDDLE FLEX
RSM2
1kΩ
RSM1
1kΩ
INDEX PRESSURE
INDEX FLEX
RSI2
1kΩ
RSI1
1kΩ
Project
Circuit Inputs
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Rev
Date
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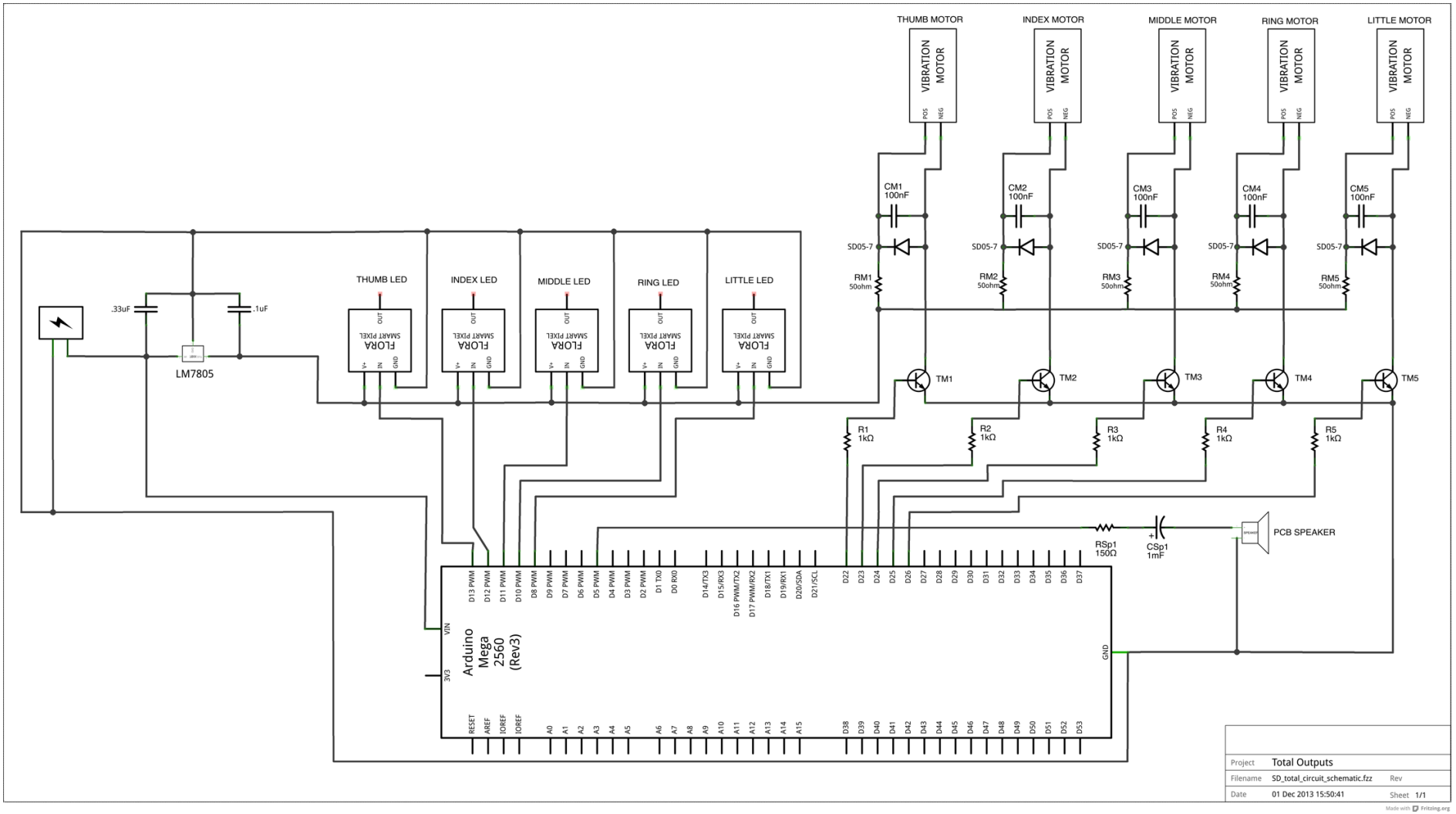
THUMB MOTOR
INDEX MOTOR
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THUMB LED
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SMART PIXEL FLORA
OUT
V+
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GND
.33uF
.1uF
LM7805
RSp1 150Ω
CSp1 1mF
PCB SPEAKER
Arduino Mega 2560 (Rev3)
VIN
3V3
RESET
AREF
GND
D13 PWM
D12 PWM
D11 PWM
D10 PWM
D8 PWM
D9 PWM
D7 PWM
D6 PWM
D5 PWM
D4 PWM
D3 PWM
D2 PWM
D1 TX0
D0 RX0
D14/TX3
D15/RX3
D16 PWM/TX2
D17 PWM/RX2
D18/TX1
D19/RX1
D20/SDA
D21/SCL
D22
D23
D24
D25
D26
D27
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D29
D30
D31
D32
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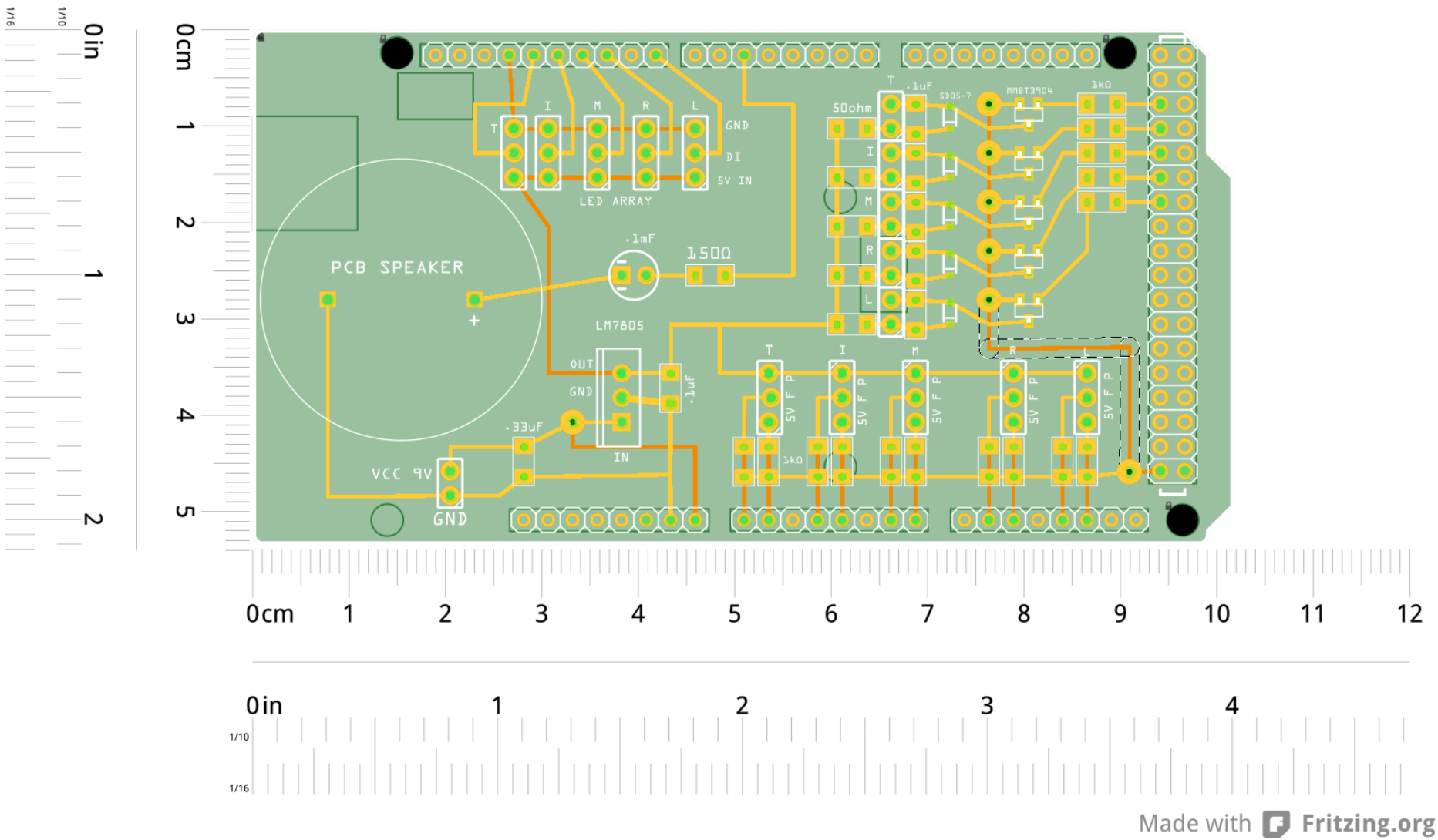


Power and Rotary Switch

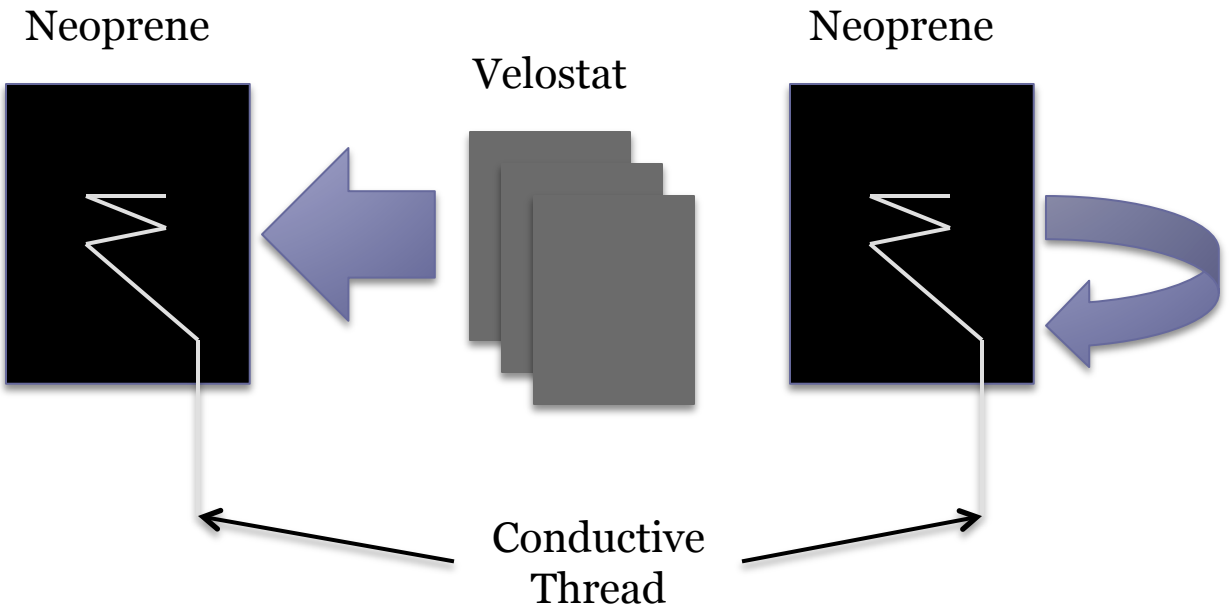
- 9V, 1.5A 2.1mm DC wall plug with on/off
  - 9V powers Arduino and DC/DC converter used to power all other components at 5V
- Rotary switch provides mode selection

Misc. Electronic Components

- 2:1 Heat Shrink will be used to bundle the wires from the finger strips
- Circuitry placed in enclosure
- Enclosure machined to provide ports for power supply and wires, open speaker to air

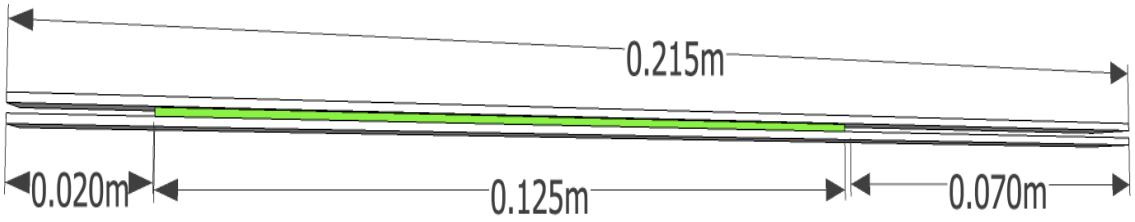
Flex and Pinch Sensor Construction

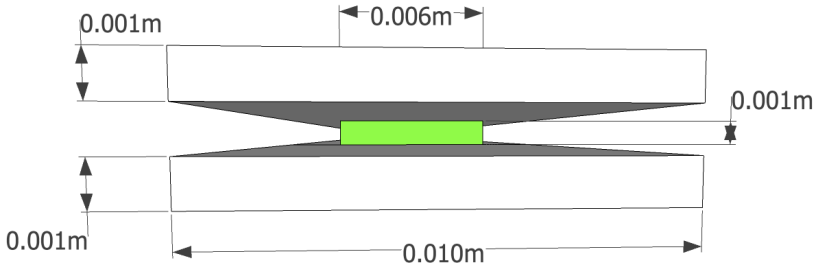
- Use neoprene to encase three Velostat strips, sandwiched between conductive thread
- Thread is soldered to leads



Discrete Sections – Finger Strip

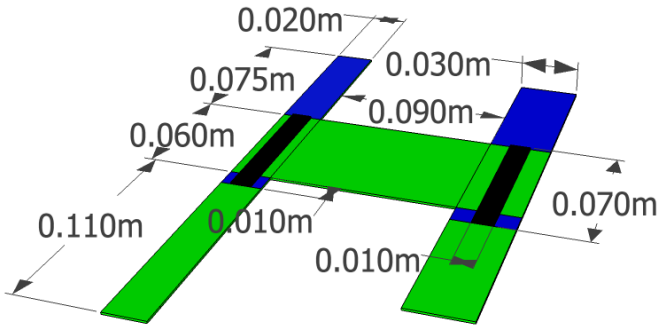
- Neoprene and encased Velostat flex sensor





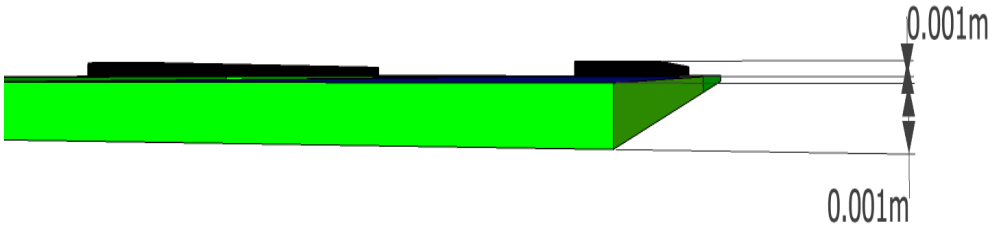
Discrete Sections

- Hand and Wrist cuff
- 1 mm Neoprene with hook-and-loop attachments
- Straps fasten around palm and wrist



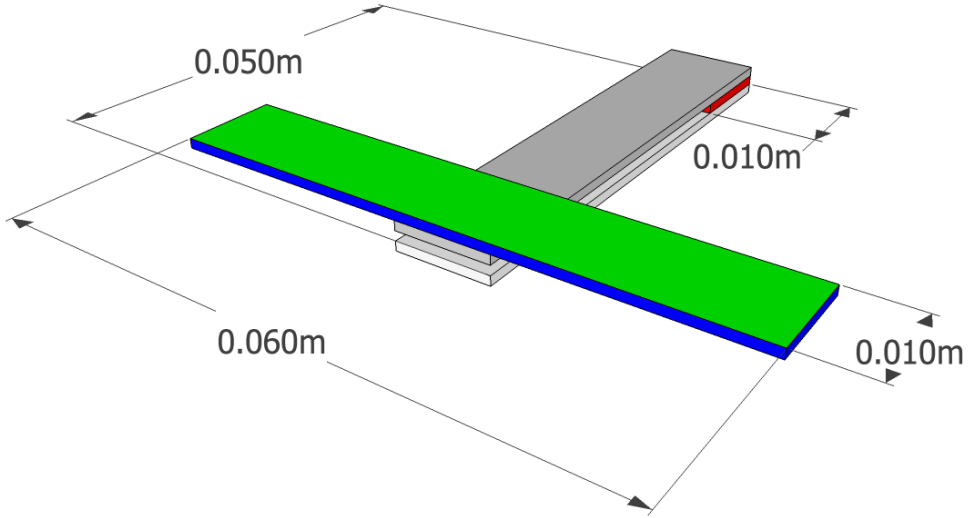
Discrete Sections

- Side view of neoprene and hook-and-loop thickness



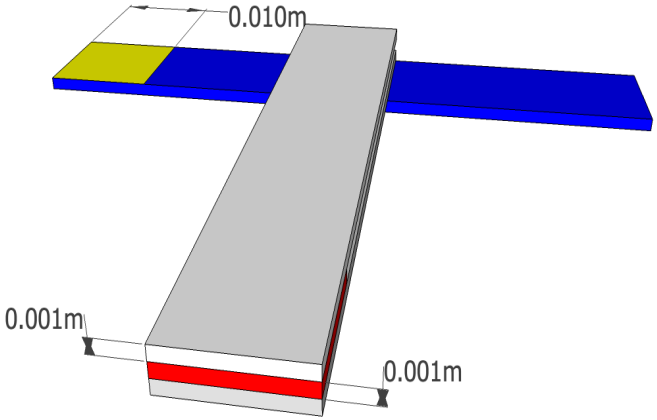
Discrete Sections – Finger Cap

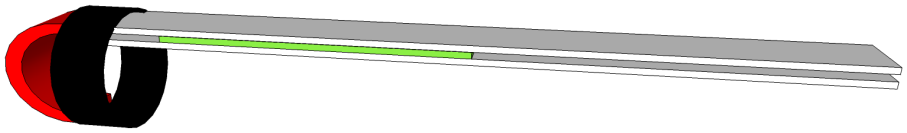
- Extension of finger strip
- Wraps around end of finger



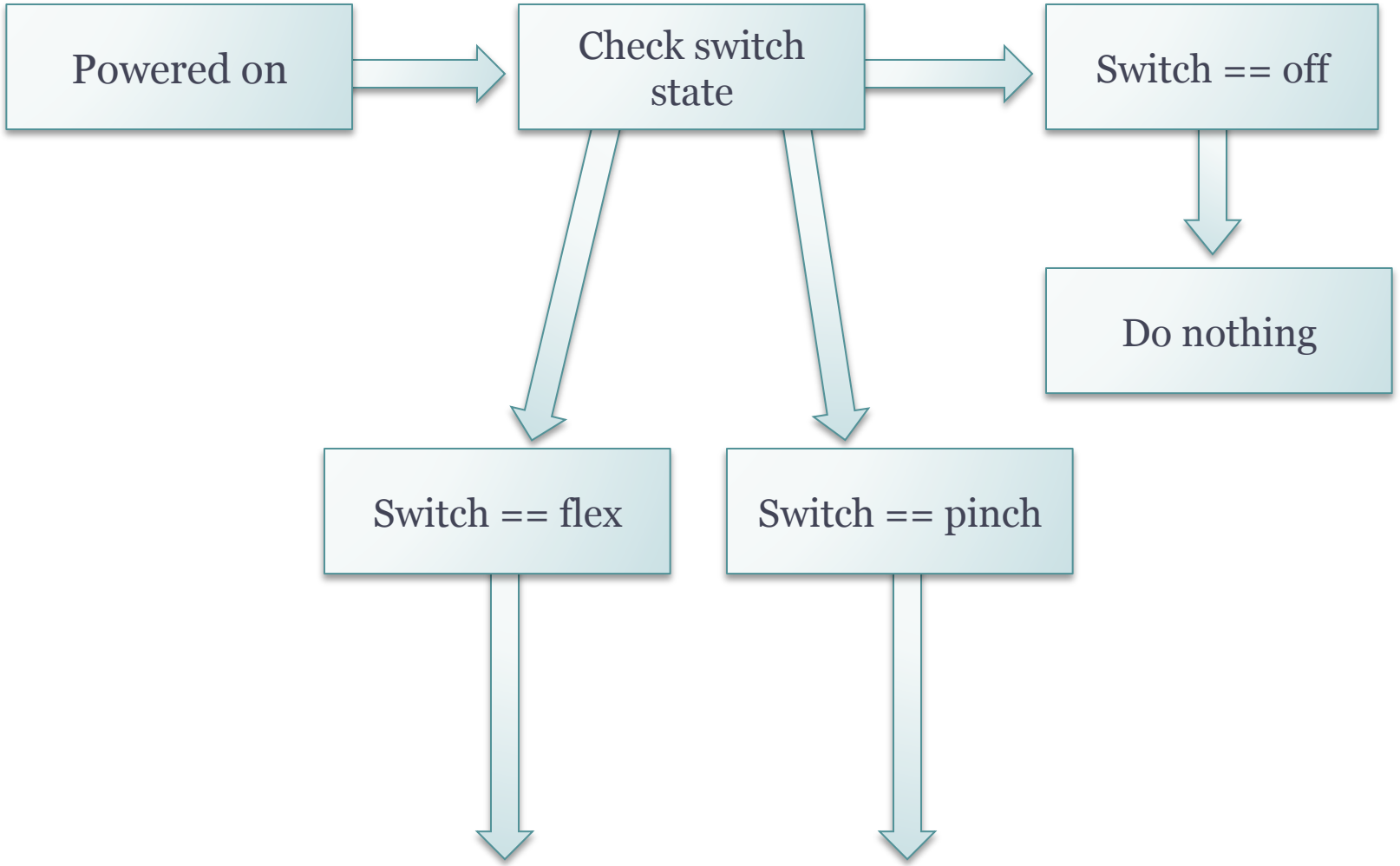
Discrete Sections – Finger Cap

- Encases the finger to form an enclosure

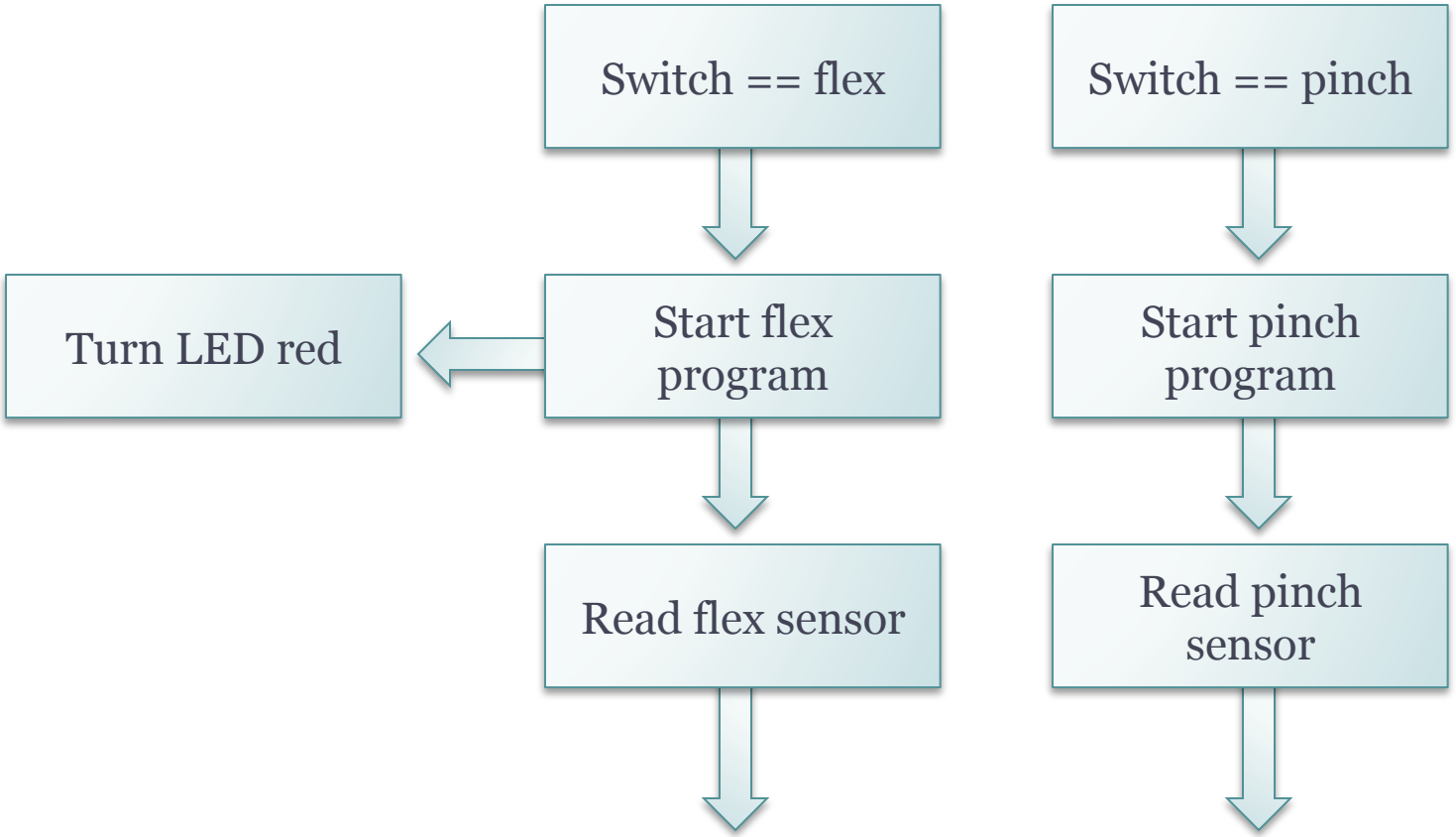




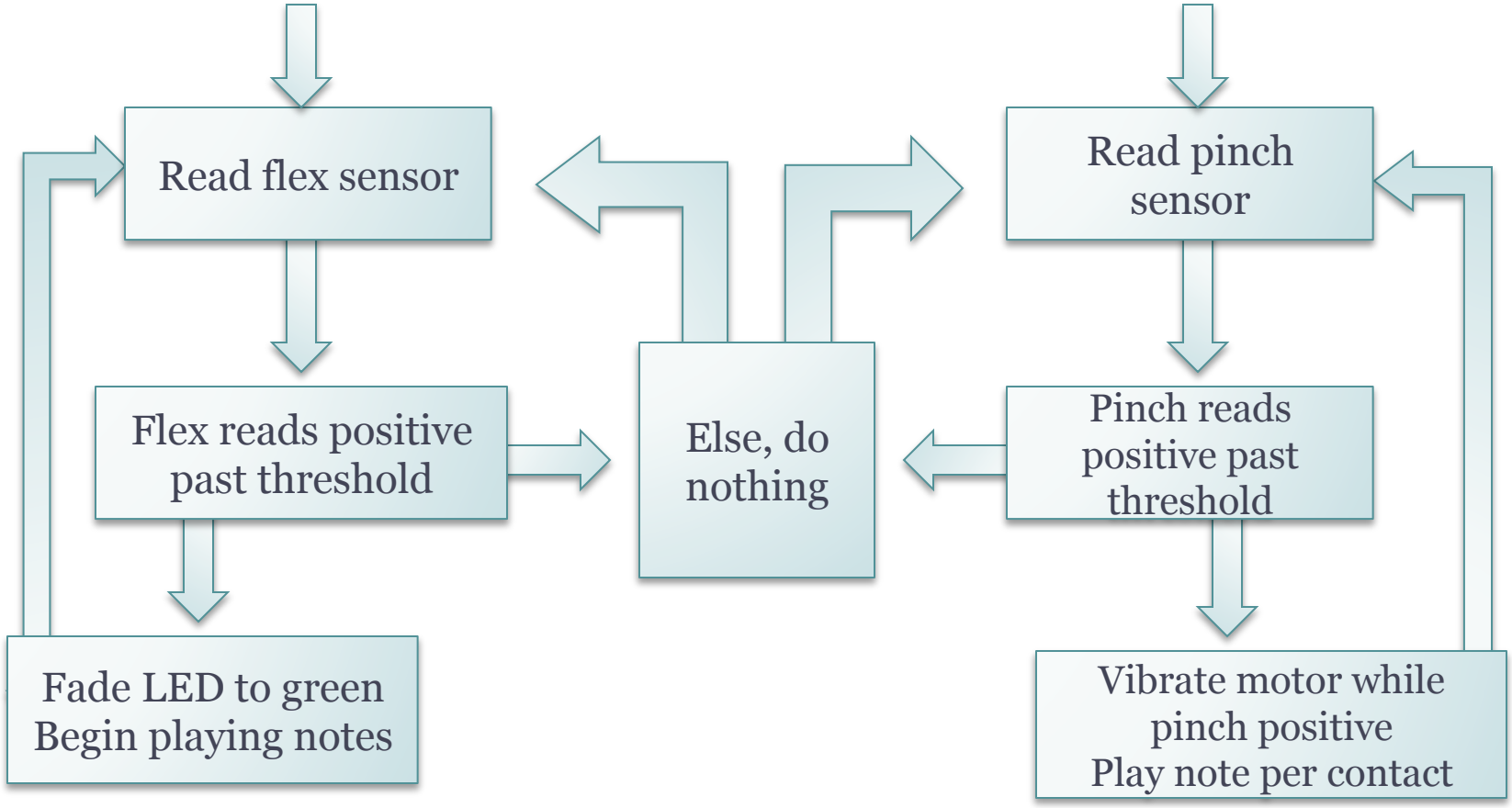
Software Flow



Software Flow



Software Flow



Bill of Materials

Item	Package	Quantity	Price/ Unit	Total Cost	Lead Time	Manufacturer	Manufacturer Part #	Supplier	Supplier Part #
Arduino Mega 2560 R3	**N/A**	**1**	**58.95**	**58.95**	**3 days**	**Arduino**	**A000067**	**Sparkfun Electronics**	**DEV-11061**
LM7805 Voltage Regulator	TO-220 IGO	1	1.25	1.25	3 days	Texas Instruments	A7805	Sparkfun Electronics	COM-00107
Barrel Jack Power Switch	M/F	1	2.5	2.5	3 days	N/A	N/A	Sparkfun Electronics	COM-11705
PCB Mount Speaker	N/A	1	1.95	1.95	3 days	Sanco Electronics	EMB-30008A	Sparkfun Electronics	COM-11089
Neopixel Strip	**60 LED/ m**	**1**	**24.95**	**24.95**	**3 days**	**Adafruit Industries**	**1138**	**Adafruit Industries**	**1138**
Barrel Power Connector	2.1 mm	1	1.86	1.86	3 days	CUI Inc.	PJ-011A	Digi-Key Corp.	CP-011A-ND
AC/DC Wall Adapter	9V, 1.5 A, 2.1 mm	1	15.95	15.95	3 days	Jameco Reliapro	S15AD090150H0650-R	Jameco	252786
12 Pos. Rotary Switch	Adj.	1	9.65	9.65	3 days	Grayhill Inc.	56D30-01-1-AJN	Digi-Key Corp.	GH5601-ND
Selector Knob	N/A	1	5.67	5.67	3 days	Grayhill Inc.	11K5028-JMNB	Digi-Key Corp.	11K5028-JMNB-ND
Knob Header	N/A	1	2.17	2.17	3 days	Samtec Inc.	ESQ-106-24-T-D	Newark	91P9155
Input Header		2	3.95	7.9	3 days	4UCON Tech. Inc.	N/A	Sparkfun Electronics	PRT-00743

Bill of Materials

Item	Package	Quantity	Price/Unit	Total Cost	Lead Time	Manufacturer	Manufacturer Part #	Supplier	Supplier Part #
Board-Board Connector	Male, 40 holes	1	2.95	2.95	3 days	N/A	N/A	Sparkfun Electronics	PRT-10158
Speaker Capacitor	.1mF, 5mm dia., 2.5 mm pitch	1	0.46	0.46	3 days	Panasonic	EEU-HD1C101	Digi-Key Corp.	P15112-ND
1K Resistors	1206	15	0.1	1.5	3 days	Panasonic	ERJ-8GEYJ102V	Digi-Key Corp.	P1.0KECT-ND
150 Ohm Resistor	1206	1	0.1	0.1	3 days	Panasonic	ERJ-8GEYJ151V	Digi-Key Corp.	P150ECT-ND
50 ohm Resistors	1206	5	0.85	4.25	3 days	Vishay	TNPW120650R0BEEN07	Mouser Electronics	71-TNPW120650R0BEEN
.1uF Capacitor	1206	6	0.1	0.6	3 days	Samsung Electromechanics	CL31B104KBCNNNC	Digi-Key Corp.	1276-1017-1-ND
.33uF Capacitor	1206	1	0.23	0.23	3 days	Samsung Electromechanics	CL31B334KBFNNNE	Digi-Key Corp.	1276-1138-1-ND
SD05-7 Diode	SOD-323	5	0.41	2.05	3 days	Diodes Inc.	SD05-7	Digi-Key Corp.	SD05DICT-ND
Transistor	SOT23	5	0.15	0.75	3 days	Fairchild Semiconductor	MMBT3904	Digi-Key Corp.	MMBT3904FSCT-ND
Hook-Up-Wire	22 AWG, stranded, 25 ft.	1	2.5	2.5	3 days	Sparkfun Electronics	PRT-08022	Sparkfun Electronics	PRT-08022
Heat Shrink	2:1, 1 in., 1 ft. segments	10	1.81	18.1	3 days	Sumitomo Electronics	AMS-DTL-23053/5	Heatshrink.com	5121010
Hand Neoprene	Smooth back, 939 sq.cm., 1mm thick	1	9.93	9.93	3 days	Small Parts	NEOHS-1MM12I12I60A	Amazon.com	N/A

Bill of Materials

Item	Package	Quantity	Price/ Unit	Total Cost	Lead Time	Manufacturer	Manufacturer Part #	Supplier	Supplier Part #
Sensor Neoprene	Smooth back, .381 mm, .836 sq.m	1	17.4	17.4	3-7 days	Kmac Plastics	N/A	N/A	N/A
PCB	**N/A**	**1**	**32.74**	**32.74**	**14+ days**	**Fritzing Fab**	**N/A**	**N/A**	**N/A**
Velostat	.1 mm thickness, 12x36 in.	1	1.95	1.95	7 days	3M	N/A	lessemf.com	LE-1234
Vibration Motors	10 mm dia.	5	1.95	9.75	3 days	Precision Microdrives	310-101	Adafruit Industries	1201
Hook Strip	.5x75 in	1	8	8	3 days	Uline	S-19438	Uline	S-19438
Loop Strip	.5x75 in	1	8	8	3 days	Uline	S-19439	Uline	S-19439
Conductive Thread	30 ft bobbin	1	2.95	2.95	3 days	N/A	N/A	Sparkfun Electronics	DEV-10867
Enclosure	N/A	1	7.95	7.95	3 days	Everest Case	N/A	Sparkfun Electronics	PRT-11366
Standoffs	3/8", 4-40 tooled, 10 pack	1	2.95	2.95	3 days	N/A	N/A	Sparkfun Electronics	PRT-10461
4-40 Phillips Head Screw	10 pack	1	1.5	1.5	3 days	N/A	N/A	Sparkfun Electronics	PRT-10450
Glove Labor Est.		1 hr.	$50	50				Independent Contractor	
Electronics Assembly		2 hrs.	$100	200				WUSM Electronics Shop	

Bill of Materials

- Total cost: $519.41
- Manufacturing costs are rough estimates and will have to be finalized
- Several points of potential cost reduction for future production

Weight on Hand Analysis

Component	# per hand	Volume (cm^3)	Weight/density of individual component	Weight on hand
0.2 mm Velostat (0.65 x 7 cm)	15	0.091	1	1.365
0.2 mm Velostat (0.5 x 1.5 cm)	15	0.015	1	0.225
1 mm Neoprene (1 x 21.5 cm)	10	2.15	1.3	27.95
1 mm Neoprene Cuff	1	40	1.3	52
0.5 mm Neoprene (0.6 x 12.5 cm)	10	0.375	1.3	4.875
0.5 mm Neoprene (0.6 x 1 cm)	10	0.03	1.3	0.39
LEDs	5	n/a	1	5
Vibrational Motor	5	n/a	1.2	6
Velcro Straps (finger)	5		3	15
Velcro Strap (hand)	1		5	5
Total Weight on Hand (g)				117.805

Safety

- Sanitation is our primary safety concern
  - Transmission of disease amongst patients is unacceptable
  - Neoprene is fluid resistant and easily cleaned
  - Instructions on cleaning drop risk from serious to low
- Mechanical injury to patients (over tightening) is possible, but rigorous training standards will help prevent this
- High currents pose threat
  - Mode selector limits max current draw
  - All potential patient-system interfaces are insulated

Actuator Safety

- Audio can't be above 80 dB
  - We have limited current across the speaker, not operated at full power
- LED brightness
  - Max 1.4 cd
  - Can limit with programming
- Motor vibration
  - Hard to judge
  - We have limited the vibration amplitude to about 1.4 g

Conclusions

- Did we meet goals?
  - Yes – proof of concept device, easily built and tested
  - Weight and feedback level constraints controlled
  - Device is safe
  - Device fits at least 90% of people
  - Doctor/Therapist has some control over operation
- Future plans – consult with Dr. Carter to pursue manufacture of prototype and testing for effectiveness
- Also optimize cost and enhance some design features

Conclusions

- Intellectual Property
  - Research device – no interest in monetizing
  - May pursue a utility patent or model to prevent monetization by others
- What did we learn?
  - Design is hard…
  - Circuits, CAD, analysis, part searches…
  - Teamwork and focus are key to completing projects
- What would we do differently?
  - Be more open to initial designs
  - Streamlined design from beginning

Thank you!
Questions?