APPENDIX A

DESIGN OF A LOW-COST, OPEN-SOURCE MYOELECTRIC SENSOR CIRCUIT FOR THE RASPBERRY PI

A.1 Overview

The EMG Pi Shield (Fig. A.1) is a printed circuit board (PCB) that allows for simple and low-cost integration of electromyography (EMG) sensors and piezoresistive force/pressure sensors with a Raspberry Pi. Using this board, signals from the EMG and pressure sensors can be used for control of and integration with the Open-Source Leg prosthesis, as in Chapters 2, and 4. The PCB design described in this appendix will be open-sourced and made available at opensourceleg.org, along with relevant software files.

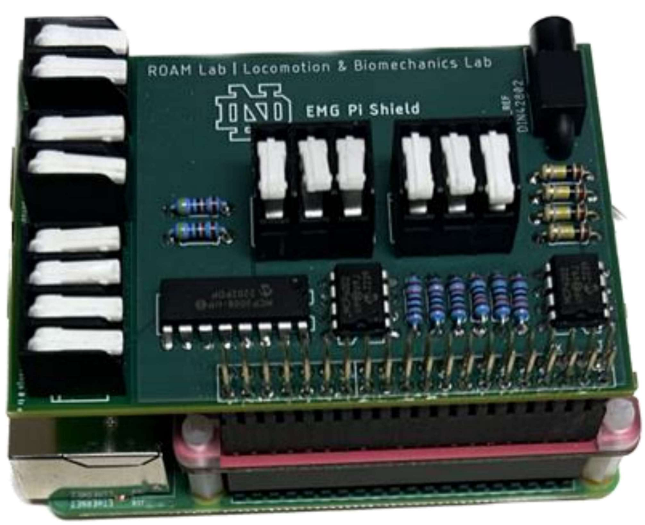


Figure A.1. The custom-built low-cost myoelectric sensor circuit, known as the EMG Pi Shield, is stacked on top of the Raspberry Pi microcomputer.

This board was designed to have the same footprint as the Raspberry Pi and attaches and communicates with the Pi using the general-purpose input/output (GPIO) interface. Therefore, this board does not need a dedicated power source, as it is designed to share the same DC power source as the Raspberry Pi it is connected to.

A.2 Components

A full list of components (with part numbers and corresponding distributor options) is shown in Table A.1. The circuit is designed to convert raw EMG signals from analog to digital to be read by the Raspberry Pi. Raw EMG signals, which are voltage differences or electrical potential differences between two electrodes, are centered about 0 volts and have positive and negative values. It is typical in EMG signal processing to rectify and smooth these values, such that all readings are positive. If the raw EMG signal is sent to the analog-digital converter used in this circuit (MCP3008), only positive signal values are kept, and all readings below 0 are clipped

TABLE A.1

BILL OF MATERIALS FOR EACH EMG PI SCHIELD PCB.

Low Cost EMG Pi Shield Bill of Materials						
Ref. ID	**Description**	**Manufacturer Part #**	**Distributer**	**Quantity (per board)**	**Unit Price**	**Total Price**
Circuit components						
R1	4.7 kOhm Resistor	CCF554K70FKE36	Mouser	2	$ 0.27	$ 0.54
R2	10 kOhm Resistor	NFR25H0001002JR500	Mouser	6	$ 0.38	$ 2.28
R3	100 kOhm Resistor	HVR3700001003JR500	Mouser	4	$ 0.40	$ 1.60
OA	Dual Op-Amp	MCP6002-I/P	Mouser	2	$ 0.40	$ 0.80
ADC	10-bit ADC	MCP3008-I/P	Mouser	1	$ 3.12	$ 3.12
Connector components						
Pressure Pins (1,2)	2 Pin Latch Terminal	15898	Sparkfun	2	$ 1.60	$ 3.20
EMG Pins (1,2)	3 Pin Latch Terminal	15899	Sparkfun	2	$ 1.60	$ 3.20
Spare Signal Pins	4 Pin Latch Terminal	15900	Sparkfun	1	$ 1.60	$ 1.60
N/A	GPIO 40-Pin Header	16764	Sparkfun	1	$ 2.25	$ 2.25
DIN42802	Female DIN42802	36619	P1 Technologies	1	$4.12 (in 2020. Seek Quote)	$ 4.12
Manufactured components						
EMG Shield PCB	unpopulated PCB	N/A	OSH Park	N/A	$ 11.42	$ 11.42
					Total Price/board:	**$ 34.13**

to 0. Therefore, even before rectification, this circuit adds a baseline voltage to the EMG signal, such that the readings are centered about 2.5 Volts and values are not clipped.

The detailed schematic for this circuit is shown in Fig. A.2. Two identical dual operational amplifiers (OpAmps, MCP6002) are used in this circuit, but for different purposes. The first set of OpAmps are configured as voltage dividers via a voltage follower circuit, splitting the difference between the +5V rail and the ground rail with two identical 10 kOhm resistors, resulting in a +2.5V output,

$$V_{out1} = V_{in1}\left(\frac{R_j}{R_i + R_j}\right) = \frac{1}{2}V_{in1} \quad \text{provided} \quad R_i = R_j, \tag{A.1}$$

where $R_i = R_j = 10$ kOhms and V_{in1} is 5V provided by the Raspberry Pi. The second set of OpAmps takes the 2.5V and adds it to the incoming EMG signal via a non-inverting summing amplifier, governed by

$$V_{out2} = \left(1 + \frac{R_x}{R_y}\right)\frac{1}{2}(V_{EMG} + V_{2.5}) \tag{A.2}$$

$$V_{out} = V_{EMG} + V_{2.5} \quad \text{provided} \quad R_x = R_y, \tag{A.3}$$

where V_{EMG} is the voltage of the raw EMG signal, $V_{2.5}$ is the constant 2.5 voltage from the previous set of OpAmps, and $R_x = R_y = 10$ kOhms. The input voltages pass through identical 100 kOhm resistors before entering the voltage summer, and these resistors are not listed in Eq. A.3. The summed voltage (V_{out2} in Eq. A.3) is then sent directly to the analog-digital converter (ADC) via one of the available input channels. The constant voltage is later subtracted from the raw EMG signal in software. The remaining signal can then be rectified and smoothed as desired in software. EMG sensors can be powered via the 5V and ground pins of the 3-pin latch terminal, with the third pin occupied by the EMG signal line. The touchproof DIN 42802 female connector interfaces with a standard male DIN 42802 electrode wire for myoelectric

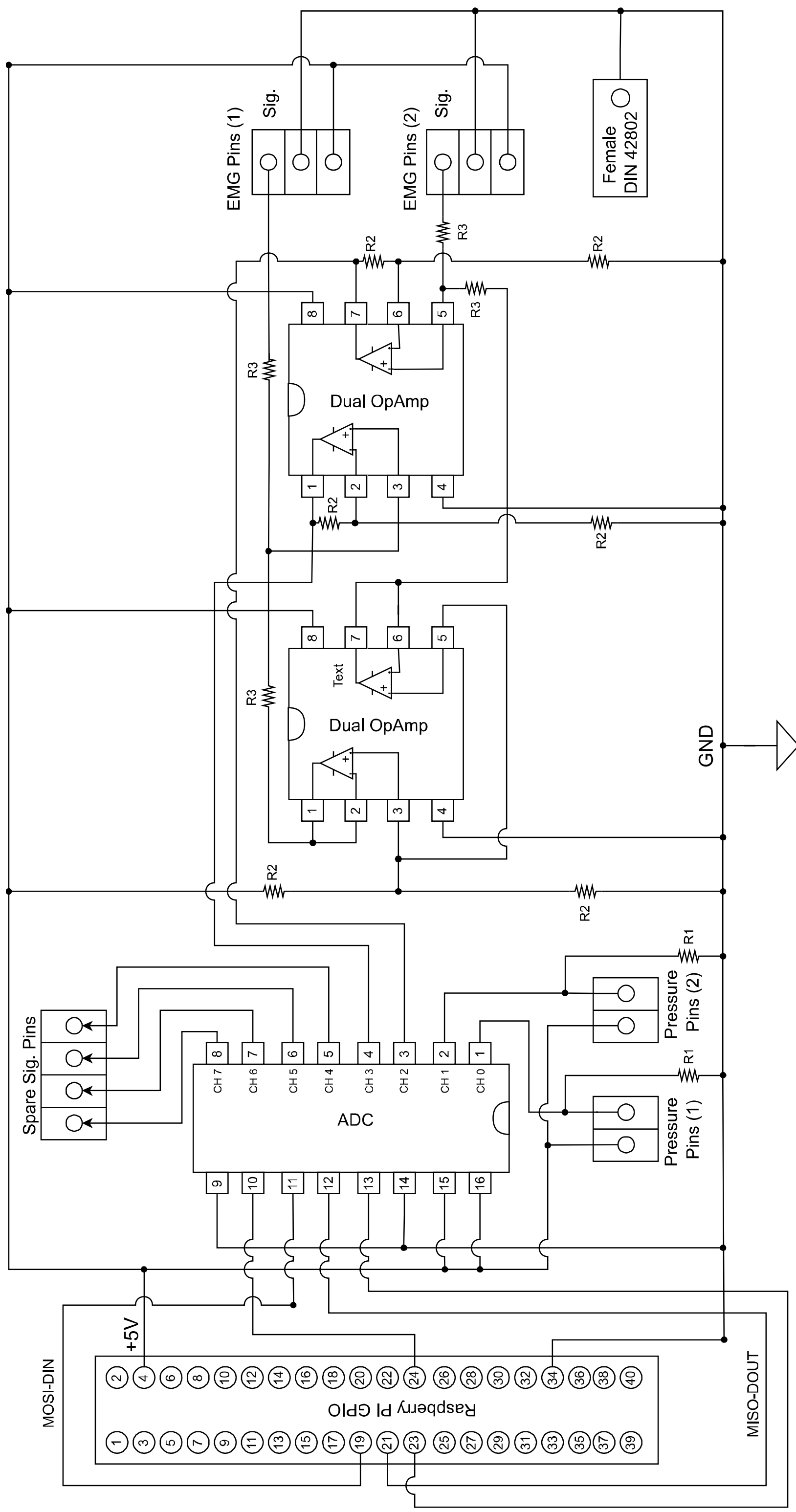


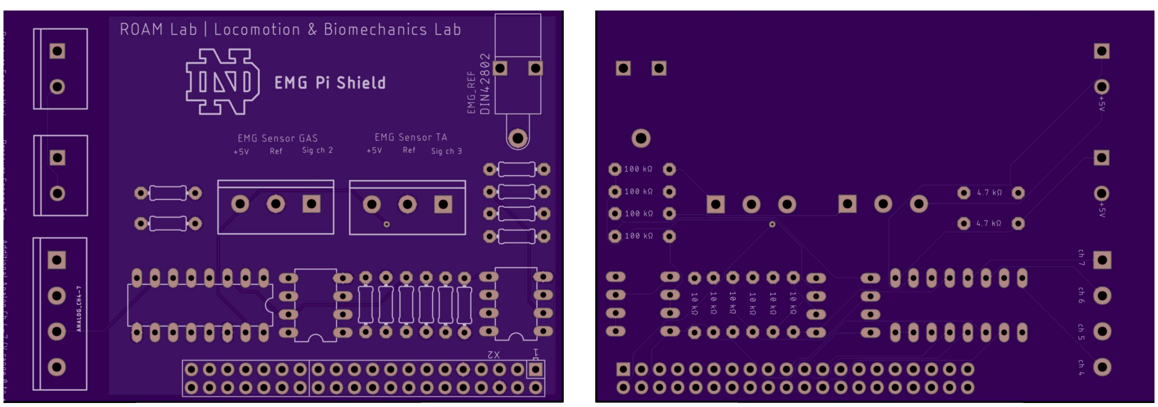
Figure A.2. A schematic of the EMG Pi Shield circuitry.

grounding.

Additionally, the signal from two FlexiForce piezoresistive pressure sensors, one for the heel and one for the toe, are attached via wired connection to the 2-pin latch terminals, and the signal is sent to available input channels of the ADC. Finally, a 4-pin latch terminal is configured to retain access to the remaining 4 signal channels of the ADC (8 channels total, 2 used by pressure sensors and 2 used by EMG sensors).

A.3 Layout

A rendering of the layout of the unpopulated board can be seen in Fig. A.3. The layout of the board does not reflect the layout of the schematic. There are no mounting holes on the board, as attachment occurs via the General Purpose Input/Output (GPIO) pins. Through OSH Park, the board can be manufactured with 2 oz copper and a thickness of 0.8 mm, but any PCB manufacturer can be used.



(a) (b)

Figure A.3. The unpopulated layout of the EMG Pi Shield on top (a) and bottom (b).

A.4 Sensor Options

A variety of EMG and pressure sensors can be used to interface with this system (Table A.2). For the EMG sensors, the primary requirement is that the myoelectric signal must be amplified before entering the signal line via the latch terminal. EMG sensors that require +5V for power may use the 5V pin of the latch terminal to do so, or an external power source can be used. In either case, the ground pin of the latch terminal must be electrically connected to the ground of the EMG sensor. This is also grounded via the PCB circuitry to the myoelectric ground electrode via the DIN 42802 connector.

The pressure sensor units described in Chapters 2 and 4 are shown in Fig. A.4. To better distribute the load from the user's foot onto the piezoelectric sensor head, Two

TABLE A.2

OPTIONAL SENSORS COMPATIBLE WITH THE EMG PI SHIELD.

Optional Compatible Sensor Choices						
Optional Compatible Sensor Choices	Description	Manufacturer Part #	Distributer	Quantity (per board)	Unit Price	Total Price
EMG (Hobby-Level)	MyoWare 2.0 Muscle Sensor	21265	Sparkfun	2	$ 39.95	$ 79.90
	MyoWare 2.0 Cable Shield	18386	Sparkfun	2	$ 5.95	$ 11.90
	Sensor Cable - Electrode Pads (3 connector)	12970	Sparkfun	2	$ 5.50	$ 11.00
	Disposable Surface Electrodes (snap)	12969	Sparkfun	1	$ 8.95	$ 8.95
					Total:	**$ 111.75**
EMG (Professional-Grade, reommended)	SX230FW special with integral touch proof DIN connectors (1.5mm) and an output connector Binder plug	SX230FW	Biometrics Ltd.	2	$405 (in 2023. Seek Quote)	$ 810.00
	Female Binder Connector	706-3216	RS	2	$ 10.15	$ 20.30
	Technomed Disposable Adhesive EMG 4-Disk Surface Electrodes (10 Sets/Box)	TNM-TE-K50430-002	MFI-Medical	1	$ 7.56	$ 7.56
					Total:	**$ 837.86**
Pressure Sensors (low-cost)	FlexiForce Pressure Sensor - 100lbs.	8685	Sparkfun	2	$ 21.50	$ 43.00
					Total:	**$ 43.00**

This list is not exhaustive, and alternative EMG and pressure sensors may be used.

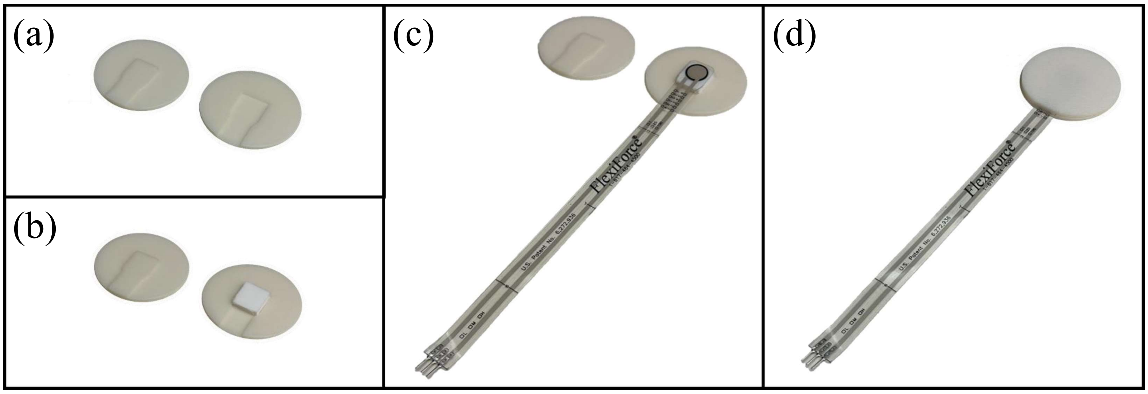


Figure A.4. Each pressure sensor unit began with 3D-printing a top and bottom plastic contact plate (a), then a layer of polyurethane rubber was added (b), the piezoelectric pressure sensor was placed (c), and the sensor head was enclosed between the top and bottom plates (d).

plastic plates (a top and bottom) were 3D-printed (Fig. A.4a), a layer of polyurethane rubber compound (Vytaflex-60) was added (Fig. A.4b), and the force sensor was placed between the plates (Figs. A.4c and A.4d). Two of these pressure units were created, one each for the heel and toe, and secured to the bottom of the cosmetic footshell (LP Variflex®foot), which was itself enveloped by a shoe. The 4.7 kOhm resistors used on the EMG Pi Shield set the sensitivity of these pressure sensors; replacing this resistor with a higher resistance will make the sensor more sensitive and decrease its active force range, per the Tekscan Flexiforce user manual.