TracKnee: Knee Angle Measurement Using Stretchable Conductive Fabric Sensors

Amanda Watson

Introduction

Knee injuries are prevalent among all demographics of patients

The biggest factor in recovery from a knee injury is adherence to the assigned rehabilitation protocol

Estimating joint angles is an important part of these protocols

Goals

Create a soft wearable device that is comfortable to wear and easy to use

Accurately calculate knee angles using a soft sensor

Research Questions

How can we measure knee angles using stretchable conductive fabric?

How can we design and fabricate a wearable device that tracks knee angles using conductive stretchable fabric and is comfortable to wear?

How accurately can we measure knee angles with our wearable device?

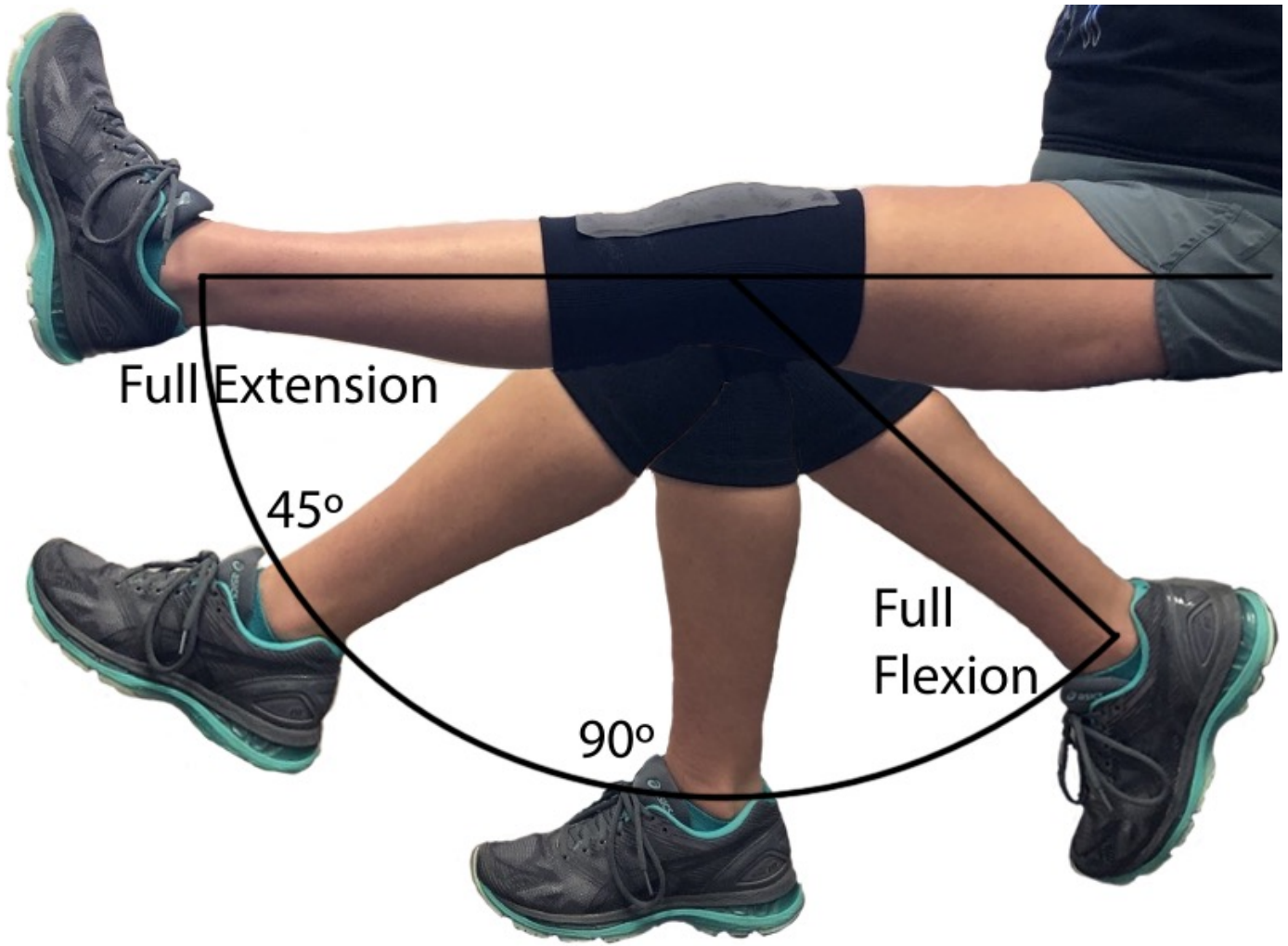
Modeling Knee Angles

Change in Length to Angle Model

Resistance to Change in Length Model

Voltage to Resistance Model

Knee Motion

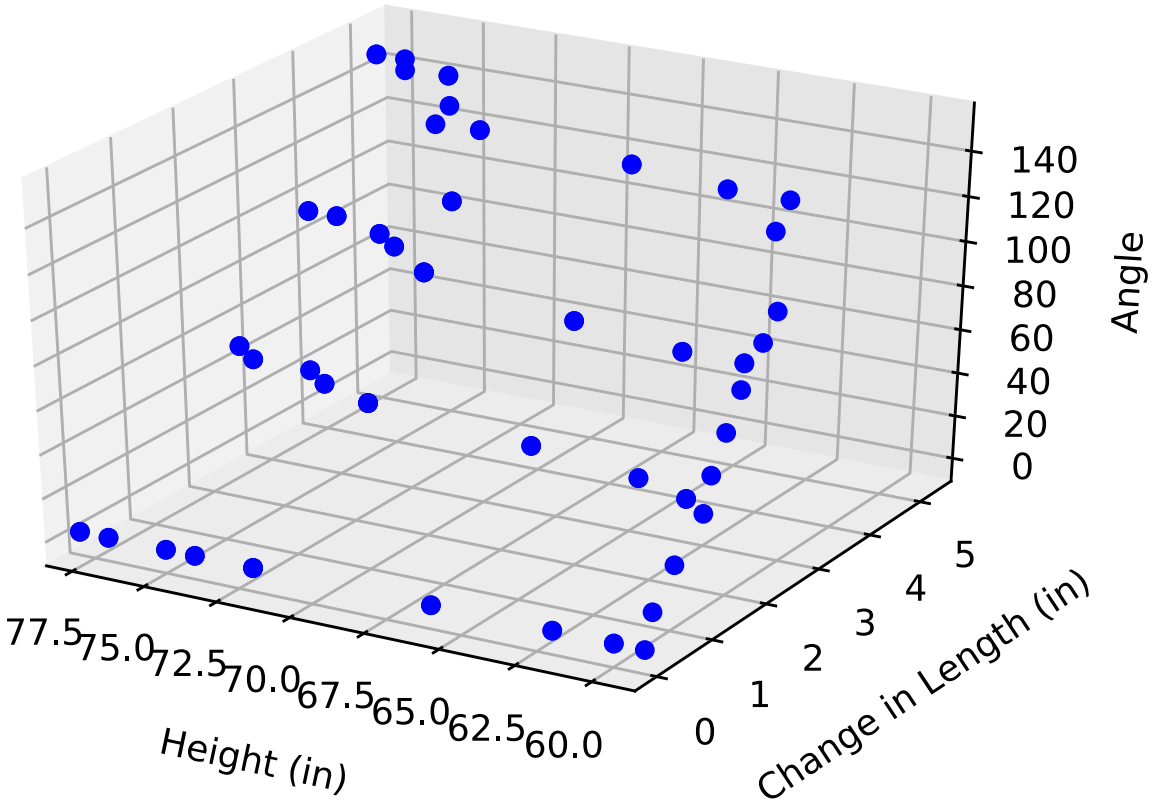


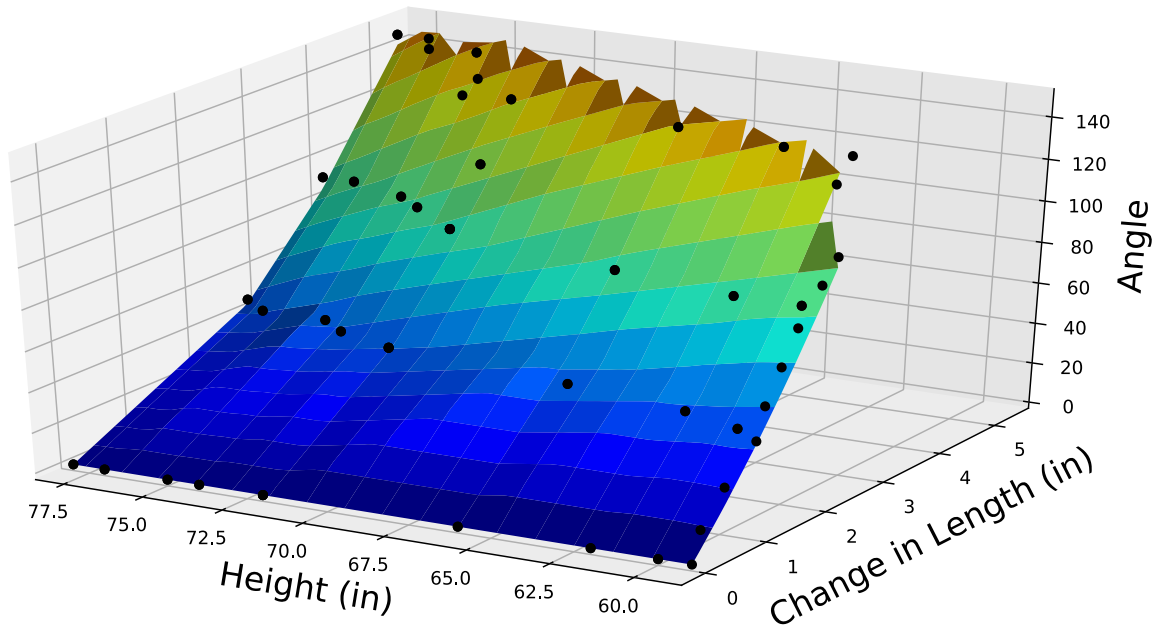
Survey Of Knee Motion

Height	Change in Length					Angle of Maximum Flexion	
	0°	45°	90°	Full Flexion Right	Full Flexion Left	Right	Left
4'11"	0"	1"	1.625"	2.5"	2.25"	125°	119°
5'0"	0"	1.5"	2.25"	2.75"	3"	142°	148°
5'2"	0"	1.5"	2.25"	3"	3"	145°	143°
5'6"	0"	1.75"	2.5"	2.5"	3.5"	148°	146°
6'0"	0"	2"	3"	3.5"	3.5"	113°	115°
6'0"	0"	2"	3"	4"	4"	139°	137°
6'2"	0"	2.25"	3.5"	4.25"	4.5"	135°	140°
6'3"	0"	2.5"	3.75"	5"	5"	148°	148°
6'5"	0"	2.5"	4"	5.25"	5"	145°	140°
6'6"	0"	2.75"	4"	5.25"	5.25"	148°	145°

Model of Change in Knee Motion

$A = 148.948L+4.428L^2-1.86251LH$





Modeling Knee Angles

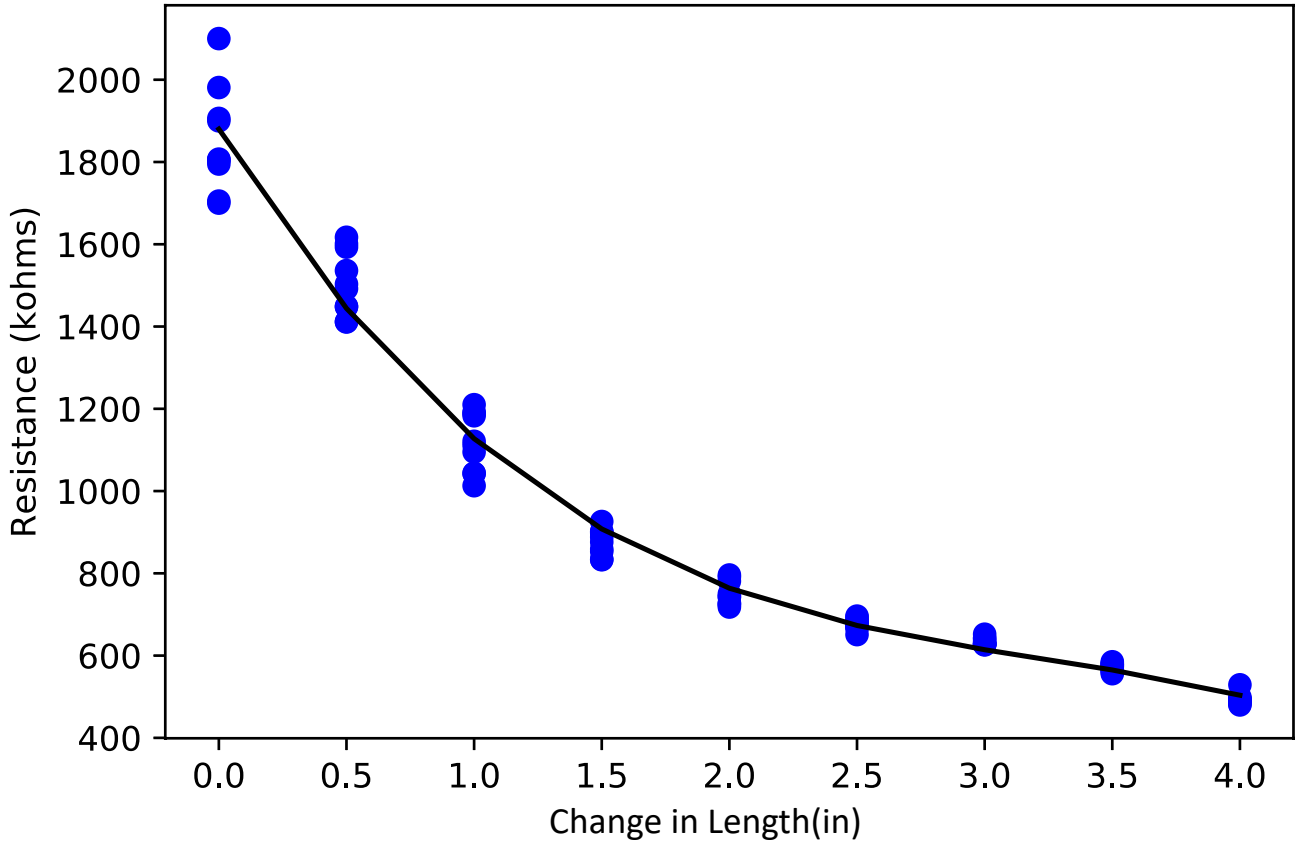
Change in Length to Angle Model

Resistance to Change in Length Model

Voltage to Resistance Model

Resistance to Change in Length

$L = -29{:}184R^3 + 282{:}126\ R^2 - 1005{:}642R + 1880.047$



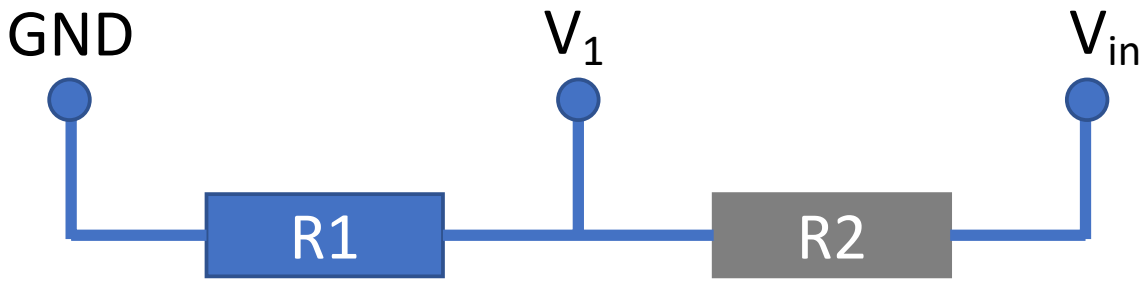
Modeling Knee Angles

Change in Length to Angle Model

Resistance to Change in Length Model

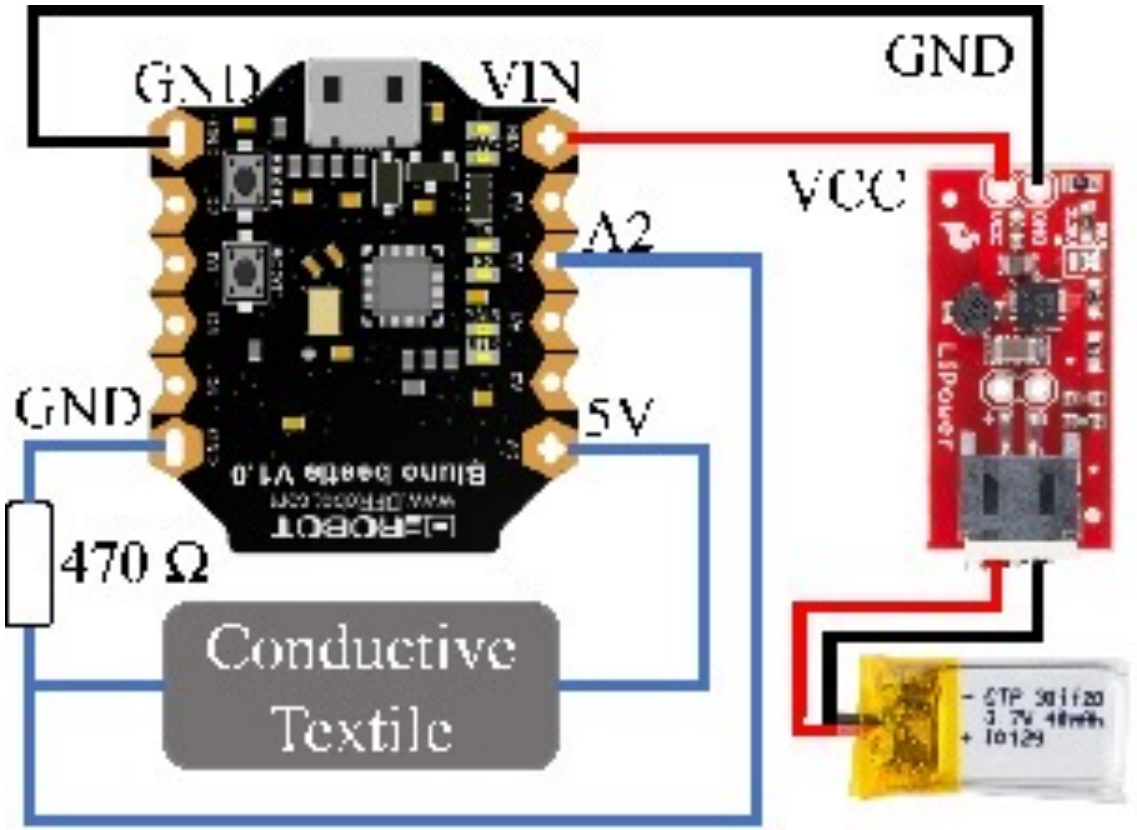
Voltage to Resistance Model

Voltage to Resistance Model

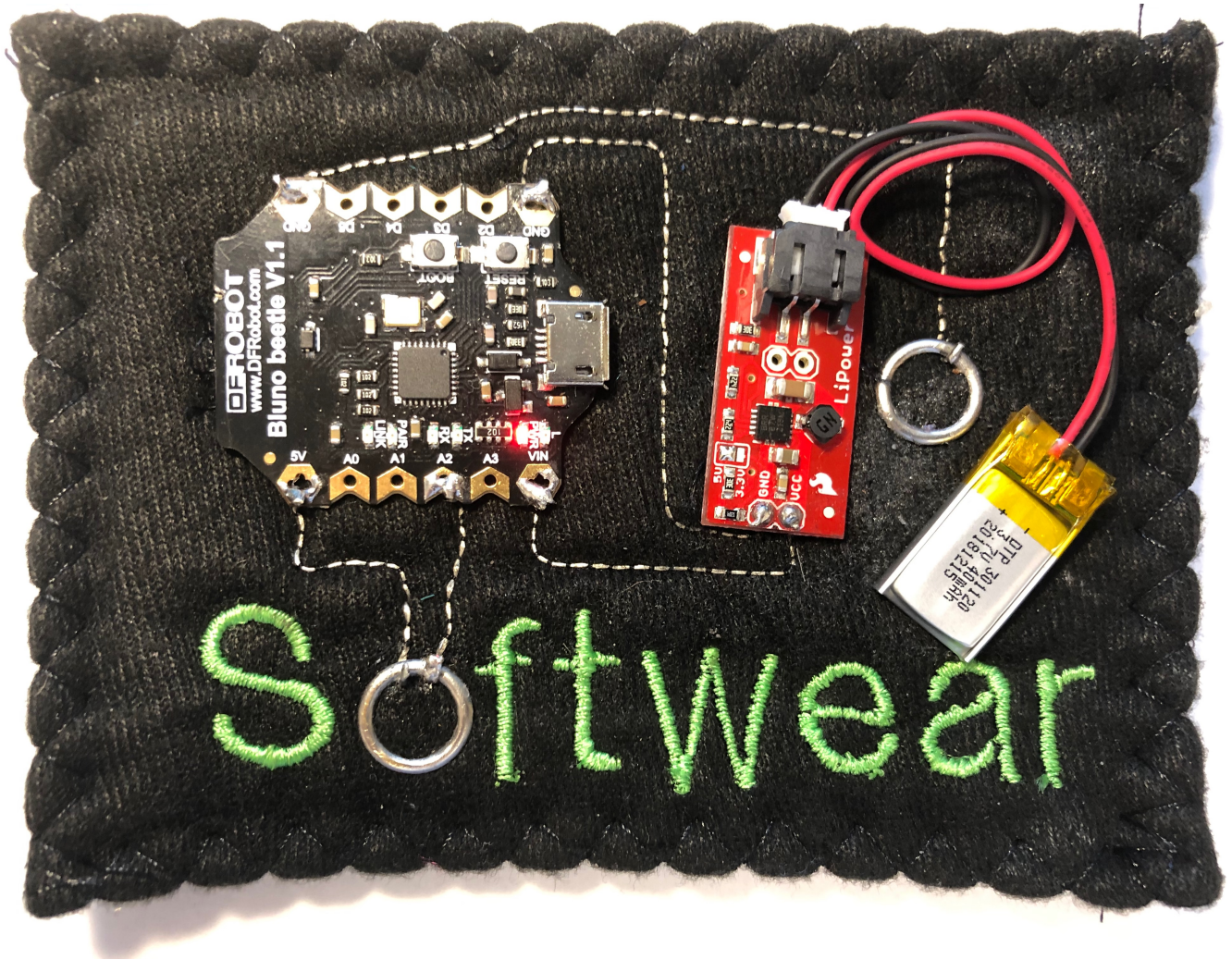


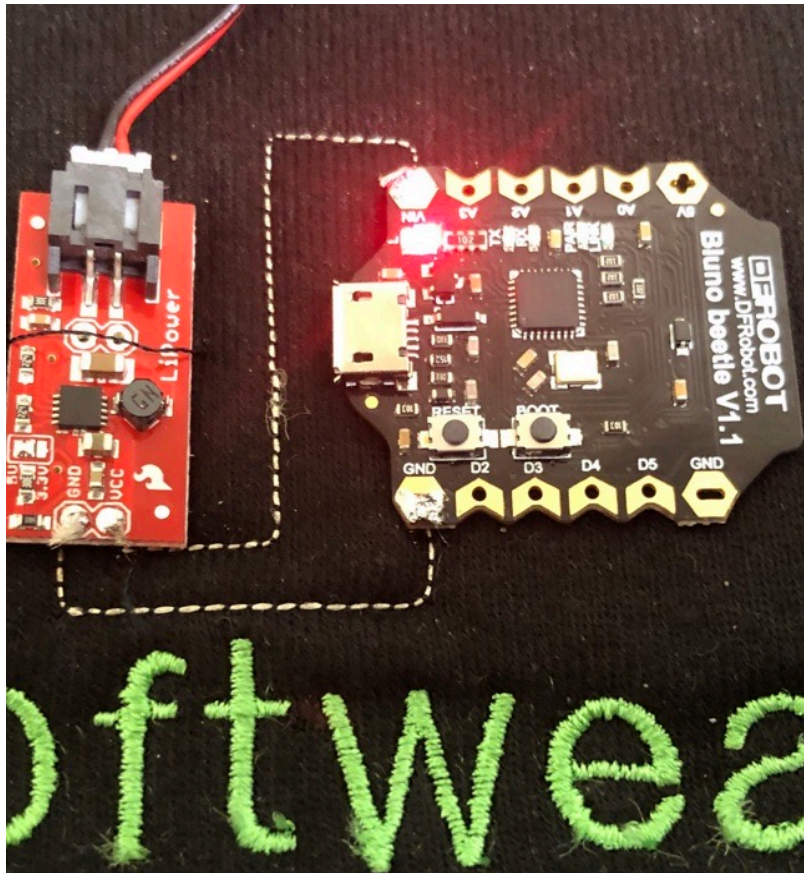
$$R_2 = \frac{V_1 * R_1}{V_{in} - V_1}$$

TracKnee Prototype Design

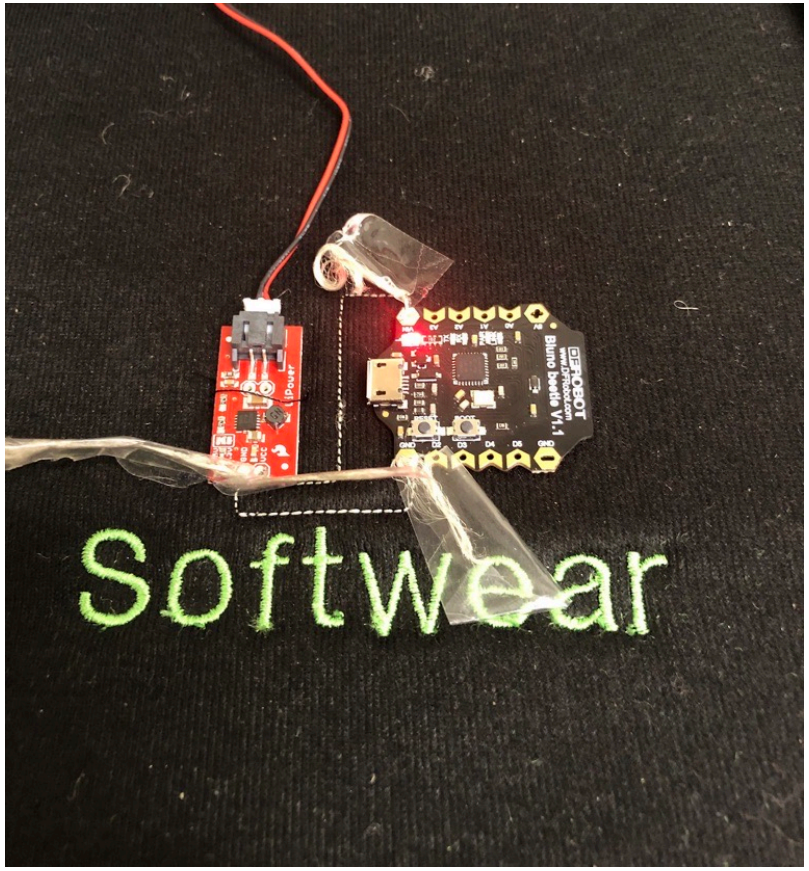


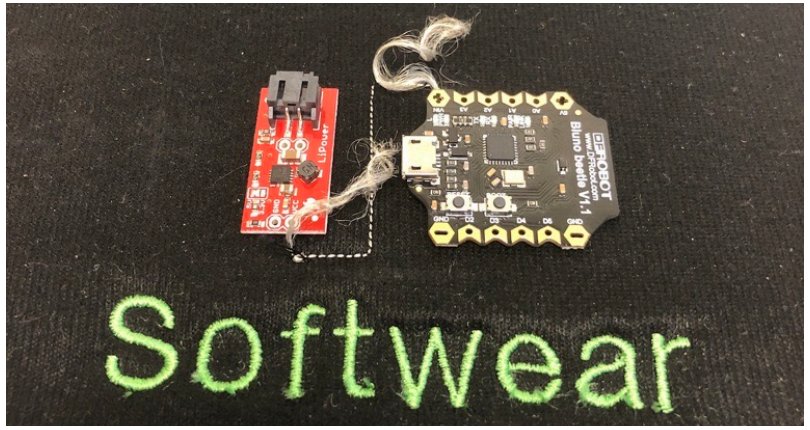
Control Patch




LiPower
GND
VCC
DFROBOT
www.DFRobot.com
Bluno beetle V1.1
RESET
BOOT
GND
D2
D3
D4
D5
GND

baby lock
Verve
Embark on a Creative Journey

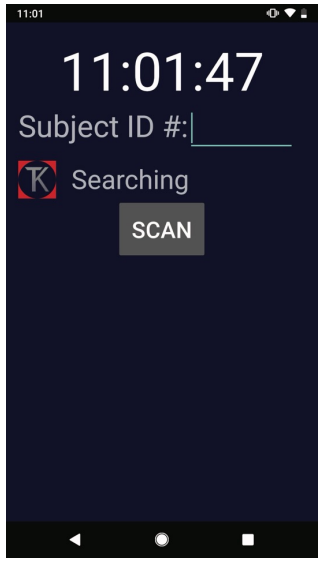

Softwear

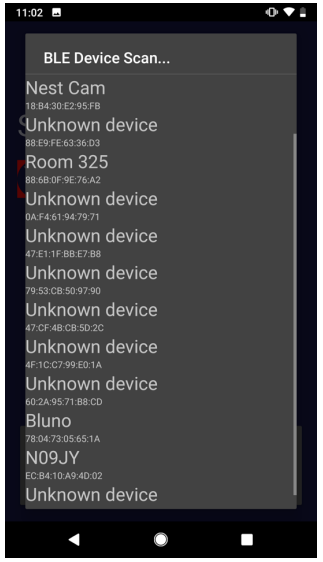

Softwear

Production

Data Collection Application

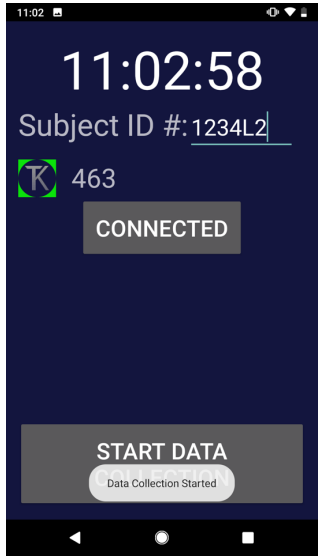
Initial State

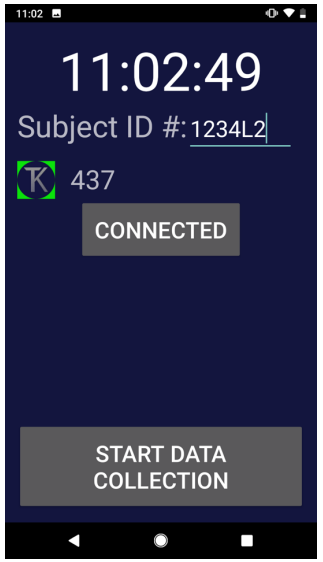




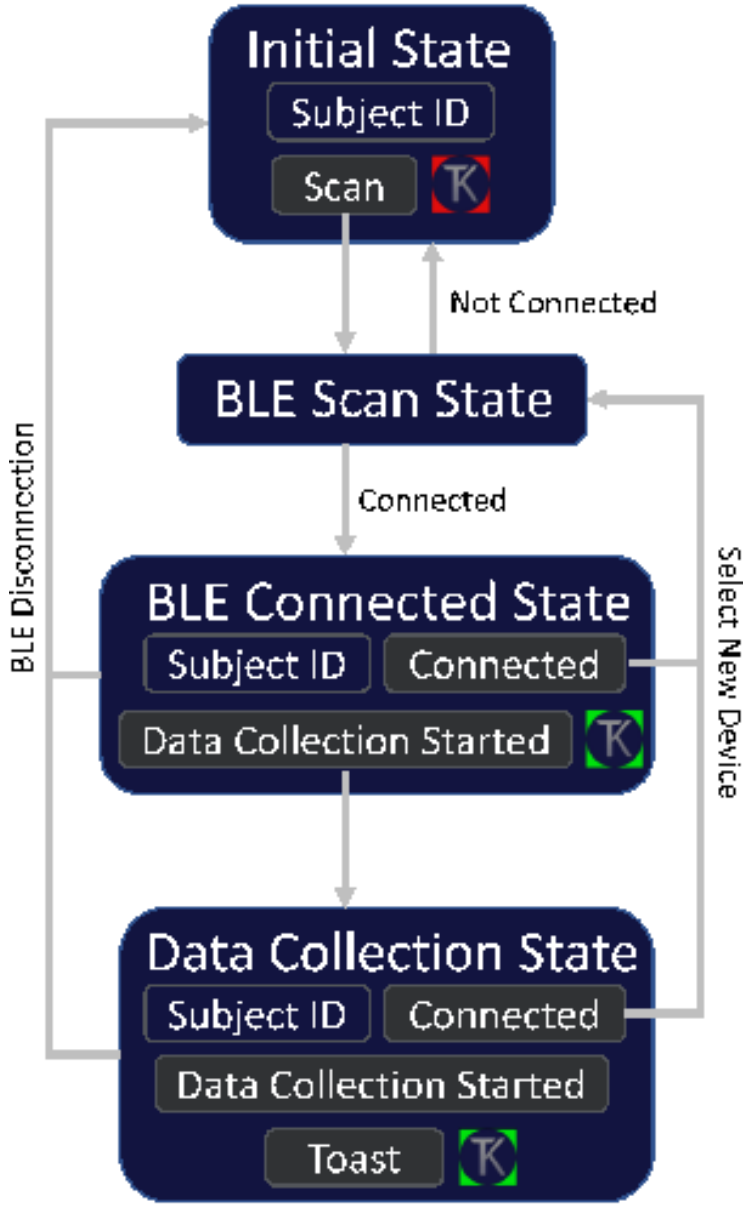
BLE Scan State

BLE Connected State



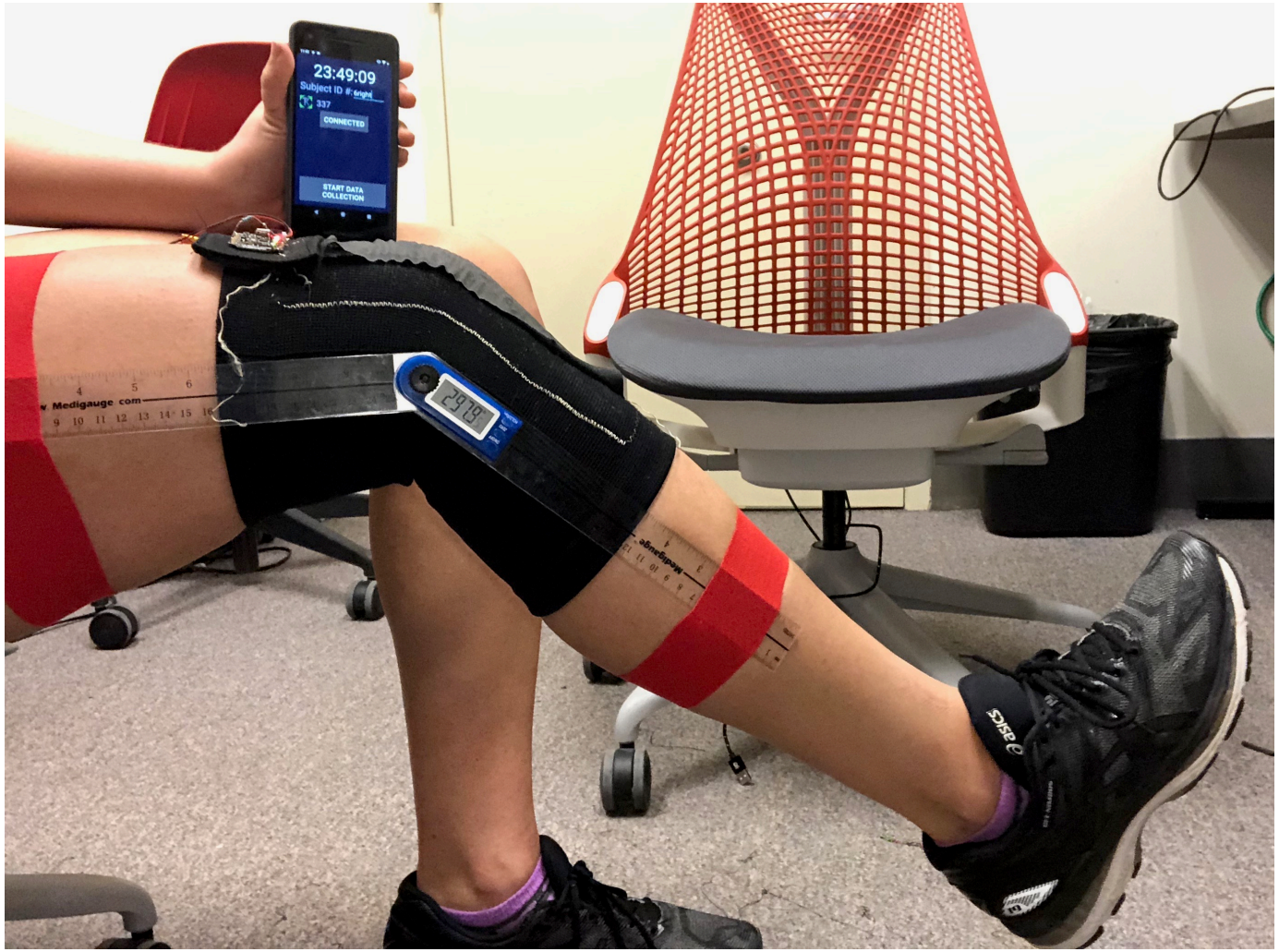


Data Collection State



User Study

- 240 total knee angles
- Knee Angles- 0°, 15°, 30°, 45°, 60°, 75°, 90°, 105°, 120°, and 135°
- All participants had a normal BMI
- Average age: 25.3
- 3 male/3 female

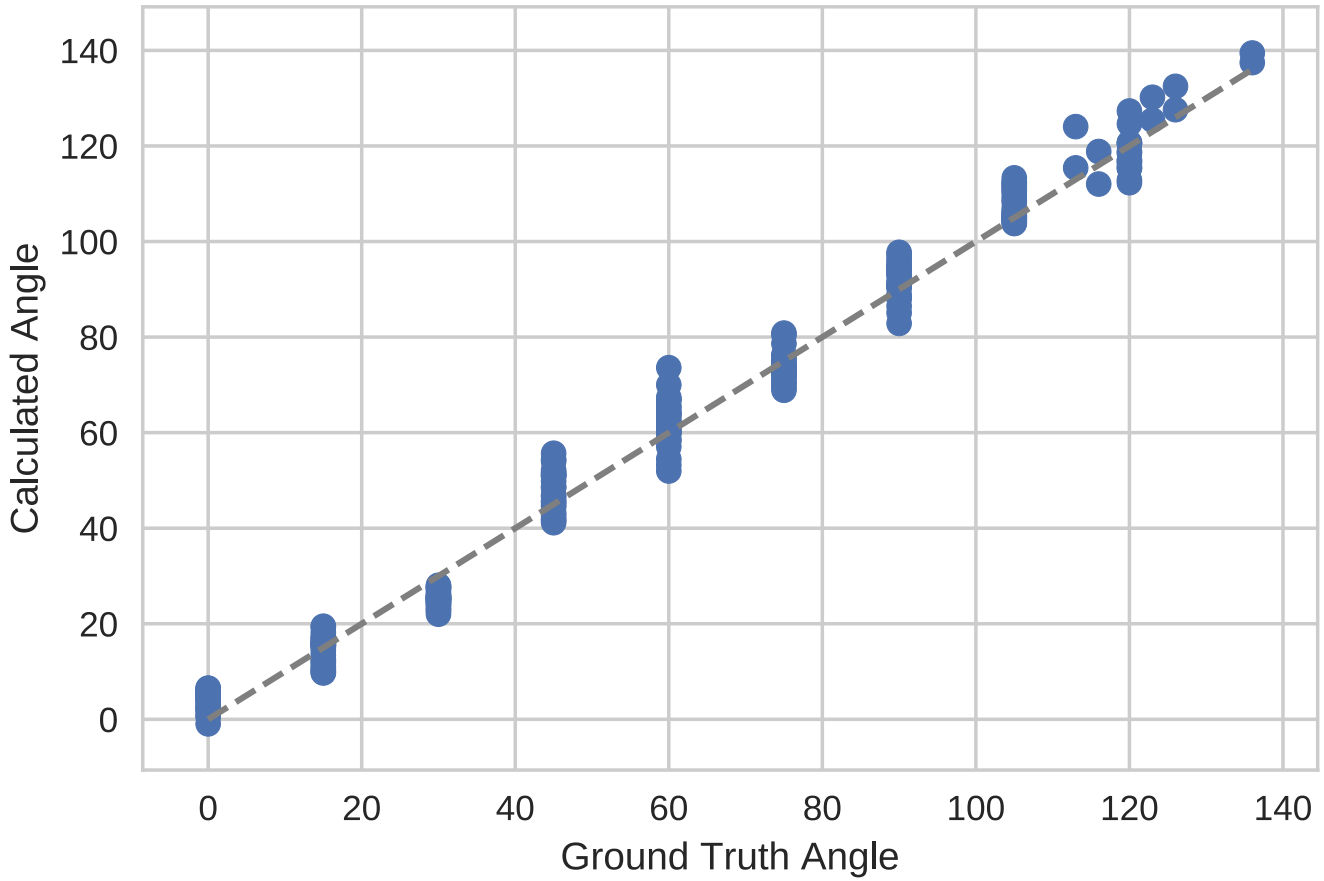


Data Collection

Participant #	Height	CLEF		Maximum Extension		Maximum Flexion	
		Right	Left	Right	Left	Right	Left
1	4’11”	2.5”	2.25”	123°	120°	−1°	0°
2	5’5”	3”	2.75”	147°	145°	0°	0°
3	5’6”	2.75”	2.5”	136°	126°	−2°	−4°
4	5’7”	3”	3.25”	123°	130°	0°	−1°
5	6’0”	3.25”	3.25”	113°	116°	−10°	−8°
6	6’0”	4”	4.25”	139°	137°	0°	0°

Results

- Accuracy: 94.86%
- Average error: 3.69 °



Results

Participant #	Height	Accuracy					Average Error
		15	12.5	10	7.5	5	
1	4'11"	94.44	86.11	80.56	63.89	41.67	3.29°
2	5'5"	94.29	88.57	77.14	60.00	40.00	3.34°
3	5'6"	100.00	80.55	66.67	58.33	50.00	3.35°
4	5'7"	91.67	83.33	72.22	52.78	41.66	3.79°
5	6'0"	94.44	83.33	69.44	47.22	33.33	3.99°
6	6'0"	94.29	82.86	54.29	37.14	25.71	4.42°
Overall		**94.86**	**84.11**	**70.09**	**53.27**	**38.79**	**3.69°**

Conclusion

- We proposed three models that can be used in succession to calculate knee angles given a voltage reading. Given a voltage reading, we first calculate the change in resistance of our conductive fabric, then its change in length, and finally the knee angle.
- We present TracKnee a sensing knee sleeve made with a conductive fabric sensor that unobtrusively measures knee angles and was created while keeping in mind the comfort of the user. Because of this, we made sure the device was comfortable, unobtrusive, and washable.
- We ran a user study in which we collected data on 240 knee angles from six individuals. We used this data to calculate knee angles using our models.
- Our results show that our model is 94.86% accurate to the nearest 15th degree angle and that our average error per angle is 3.69.