# Continuous Blood Pressure Monitoring
## With Small Footprint Pressure Sensors

**Jorge Carlos Arias Delgado, Alexandra Anthony, Nezih Pala, Vladimir Pozdin**
Florida International University
Email: jaria092@fiu.edu, aanthony@stevens.edu

## Motivation:

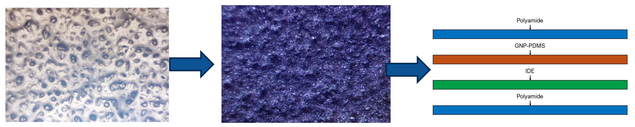
- **Hypertension is widespread.** High blood pressure (BP), also known as hypertension, affects over 1 billion people worldwide and is a leading risk factor for cardiovascular diseases, stroke, and kidney failure.
- **Our Research Solution**: Using pulse wave velocity (PWV) measurements from the dorsalis pedis artery for continuous BP monitoring and data collection, we can provide early detection and continuous monitoring methods.
- **Key Words**: **Hypertension, PWV (Pulse Wave Velocity), Hypotension, BP (Blood Pressure), PDMS (Si Polymer), GNP (Graphene Nano Platelets),**

## Sensor Fabrication:

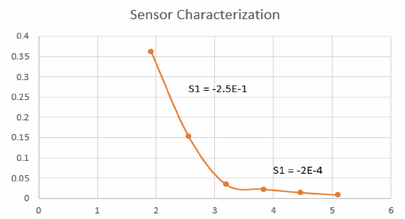
Materials Needed: **GNP, IPA, DI Water, PDMS Pre-Polymer and Curer, IDE**
(IDE not manufactured)

**Steps**

1. Mix PDMS Pre-Polymer and Curer, Cure in mold with sandpaper base.
2. Mix GNP and IPA with horn sonifier to create homogenized mixture.
3. Transfer Langmuir thin films from GNP solution to DI water via dipping
4. Deposit GNP films on PDMS, realizing sensing layer. Tape together with IDE. (2)




## Sensor Characteristics :

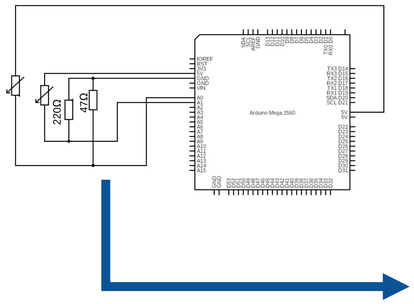



**Section 1**
-2.5E-1 $kPa^{-1}$

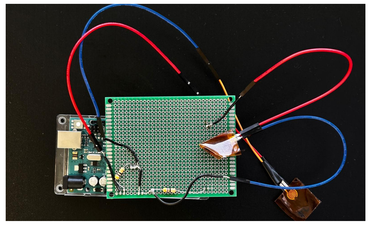
**Section 2**
-2E-4 $kPa^{-1}$

- Sensor showcased promising linearity in Section 1 and 2, showing observable change in slope.
- Resistance of sensor between 3k-250 Ohms
- Increased resolution of force gauge would create better characterization


## Circuit Design:




- Arduino Mega 2560
- Wires
- Resistors (220Ω,47Ω)
- PCP Board



## Data Acquisition and Analysis

$$(1)\ \boldsymbol{BP} = \alpha PWV^2 + \beta$$

```
// Function to calculate Blood Pressure
float calculateBP(float pwv) {
  return alpha * pwv * pwv + beta;
}
```

Qualitatively describes the relationship between BP and pulse PWV:

**α = 0.046 kPa·s²·m⁻²**

Indicates how much the blood pressure increases with the square of the PWV. It represents the sensitivity of BP to changes in PWV.

**β = 5.1 kPa**

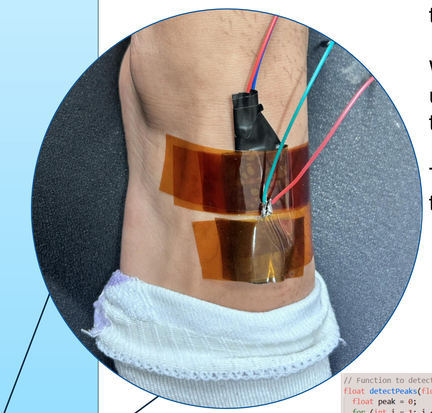
Baseline BP value, representing the BP when there is no PWV.

Thus, BP increases with the square of the speed at which the pulse wave travels through the arteries, starting from a baseline pressure.

We began by placing the sensors 25 mm apart on the **Dorsalis Pedis** artery as visualized below.

We then wrapped the sensors using a soft uniform pressure from a sock and tape to acquire the signals.

The below Arduino code (3) was used to format the data into wave forms for analysis.



*Puma Women's Quarter Crew

3

```
void loop() {
  // Read the analog values from the pressure sensors
  int sensorValue1 = analogRead(PressureSensorPin1);
  int sensorValue2 = analogRead(PressureSensorPin2);

  // Print the sensor values to the Serial Plotter
```

4

```
// Function to detect peaks
float detectPeaks(float data[], int size) {
  float peak = 0;
  for (int i = 1; i < size - 1; i++) {
    if (data[i] > data[i - 1] && data[i] > data[i + 1]) {
      peak = data[i];
    }
  }
  return peak;
}
```

5

```
// Function to calculate moving average
void calculateMovingAverage(int data[], float result[], int size, int window) {
  for (int i = 0; i < size; i++) {
    if (i < window) {
      result[i] = 0;
    } else {
      float sum = 0;
      for (int j = 0; j < window; j++) {
        sum += data[i - j];
      }
      result[i] = sum / window;
    }
  }
}
```

(5) Moving average helps to smooth out short-term fluctuations and highlight longer-term trends.

(3) Peak detection identifies significant peaks in the smoothed data.

(4) Both are used in PWV and BP calculations.

## Results:


The graph depicts a continuous acquisition of the wave forms from the Dorsalis Pedis artery with both sensors working simultaneously.

Additionally, the lines included over the peaks visualize the time interval difference for the PWV calculations.

```
Time: 23402.00, Sensor1: 436, Sensor2: 38, Moving Avg1: 436.33, Moving Avg2: 39.00, BP: 72.69
Time: 23412.00, Sensor1: 436, Sensor2: 38, Moving Avg1: 436.00, Moving Avg2: 38.67, BP: 72.69
Time: 23422.00, Sensor1: 436, Sensor2: 38, Moving Avg1: 436.00, Moving Avg2: 38.00, BP: 72.69
Time: 23433.00, Sensor1: 437, Sensor2: 39, Moving Avg1: 436.33, Moving Avg2: 38.33, BP: 72.69
Time: 23443.00, Sensor1: 436, Sensor2: 38, Moving Avg1: 436.33, Moving Avg2: 38.33, BP: 72.69
Time: 23453.00, Sensor1: 436, Sensor2: 39, Moving Avg1: 436.33, Moving Avg2: 38.67, BP: 72.69
Time: 23463.00, Sensor1: 436, Sensor2: 39, Moving Avg1: 436.00, Moving Avg2: 38.67, BP: 72.69
Time: 23474.00, Sensor1: 436, Sensor2: 39, Moving Avg1: 436.00, Moving Avg2: 39.00, BP: 72.69
Time: 23484.00, Sensor1: 436, Sensor2: 40, Moving Avg1: 436.00, Moving Avg2: 39.33, BP: 72.69
Time: 23494.00, Sensor1: 436, Sensor2: 38, Moving Avg1: 436.00, Moving Avg2: 39.00, BP: 72.69
```

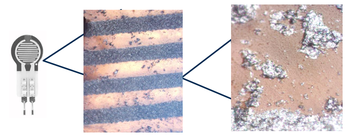
The Arduino Serial Monitor output reflects the working calculations for the moving average and BP calculations.

## Conclusion:

```
detectPeakSimpleThreshold(sensorValue);
detectPeakMovingAverage(sensorValue);
detectPeakDerivative(sensorValue);
detectPeakAdaptiveThreshold(sensorValue);
detectPeakWaveletTransform(sensorValue);
```

Future Work:

- Implementation of precise peak detection methods for more accurate BP calculations.
- Using "in-date" GNP sensitivity and higher resolution Force gauge



- Our study demonstrates the feasibility of deriving PWV from a 25mm distance on the dorsalis pedis artery to continuously calculate BP.
- Using a piezoresistive pressure sensor and an Arduino Mega 2550, **we implemented real-time data processing**, including moving average smoothing and peak detection.
- This allowed for **PWV measurement** and **continuous BP estimation**

## Acknowledgements / References

(1) Huang, Yonggang. *Relation between Blood Pressure and Pulse Wave Velocity for Human Arteries*, 18 Sept. 2020, https://doi.org/10.26226/morressier.5f5f8e69aa777f8ba5bd5f5d.
(2) Chowdhury, Azmal Huda, et al. "Flexible Piezoresistive Pressure Sensor Based on Graphene Nano Plateletes." 2023 IEEE BioSensors Conference (BioSensors). IEEE, 2023.
This research was supported by the National Science Foundation (NSF) under Award 2349464.