Phenomenon# 14 **مشاہدہ ۱۴#**

Arterial Oscillations in Blood Pressure Measurement

خون کے دباؤ کی پیمائش میں شریانوں کا ردِّعمل

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According to the World Health Organization (WHO), 43% of the population in Pakistan aged between 30 and 79 have hypertension [1]. To control and treat hypertension, it is imperative to regularly monitor blood pressure. There are various methods to do this, the most common being the auscultatory method, where a listener uses a stethoscope to hear distinct Korotkoff sounds. Another method called the oscillometric method, which relies on the physics of arterial oscillations and is used in modern electronic blood pressure machines.

The heart acts as a pump that beats in a rhythm of contracting and relaxing, pushing blood through the body in a pulsing wave. This blood carries the pressure wave into the arteries, which are elastic tubes that can stretch and compress like rubber. The behaviour of these arteries is determined by the ***transmural pressure***, which is the difference between internal and external pressure.

ابن النفیس اور ولیم ہاروے نے خون کی گردش پہ سب سے پہلے مدلل تجربات کیے۔ جسم میں خون کا دباؤ ناپنے کا سلسلہ بھی بہت پرانا ہے۔ حتّٰی کہ ہیلی نے 1773 میں پہلی دفعہ ایک گھوڑے میں خون کا دباؤ ناپنے کی کوشش کی [2]۔

Initially, upon inflation of the cuff to an appreciable pressure, the transmural pressure becomes negative as the external pressure exceeds the internal pressure. The brachial artery is shut and we effectively obstruct any blood flow.

As we start to release air, the pressure in the cuff starts to decrease. A point comes, as the heart contracts and pushes blood out, where the internal pressure in the artery momentarily becomes greater than the cuff pressure. The transmural pressure becomes positive at this point. The artery snaps open and immediately collapses again. These small, rapid changes are transferred to the cuff and we start to observe oscillations.

The cuff continues to deflate and the pressure in the cuff becomes nearly equal to the average pressure in the artery. The transmural pressure is now approximately zero. At this point, the artery shows maximum ***distensibility***, which is a measure of how easily a vessel can be stretched. Even small changes in blood pressure lead to maximum stretch in the artery's walls. This creates maximum oscillations.

Finally, as the heart relaxes, the internal pressure is at its lowest. However, as the pressure in the cuff also continues to decrease, the transmural pressure becomes positive. The artery is now fully open and is least distensible. The blood flows with least resistance and the oscillations are at their lowest.

Today we are going to use this method to see how these arterial oscillations contain much more information than just a simple pressure reading. Through this process, we will develop important computational skills and learn how to extract meaningful data from complex biological signals.

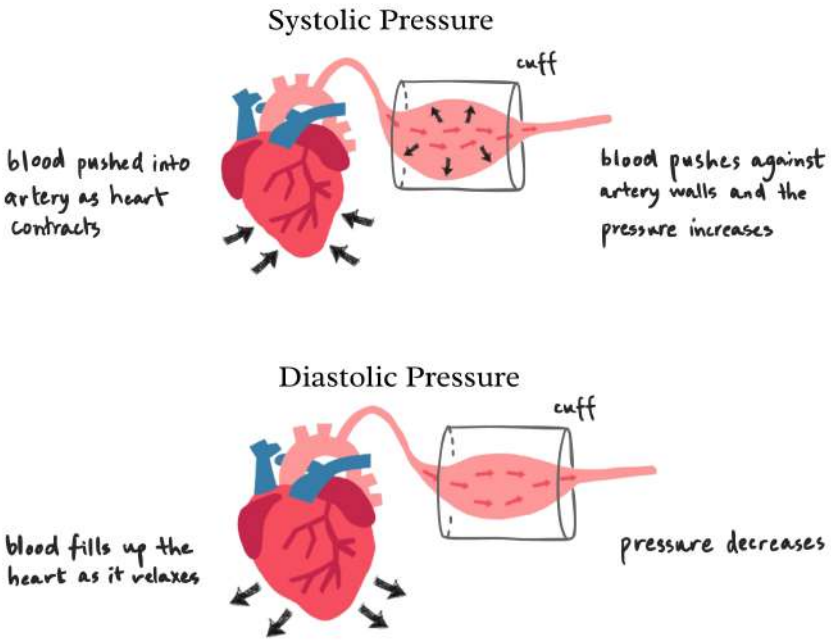


Figure 1: In the period between the systole and diastole, the pulsating blood flow periodically fills and empties the artery. The elastic artery and can expand or compress in response to blood flow. This subsequently compresses and decompresses the air in the cuff.

To observe these arterial oscillations, let's look at what we need:

1. PhysBP (developed by Qosain Scientific)
2. Laptop/PC
3. Cuff
4. Tube
5. Power supply
6. USB-C cable

Inside the PhysBP, we have two pressure sensors as shown in Fig. 2. One is a pre-calibrated sensor called the PhysBar. This pressure sensor is interfaced with a circuit that cleans the signal and produces a digital signal that is read by the PhysLogger, a data-logging software. A typical output can be seen in Fig.3 (top).

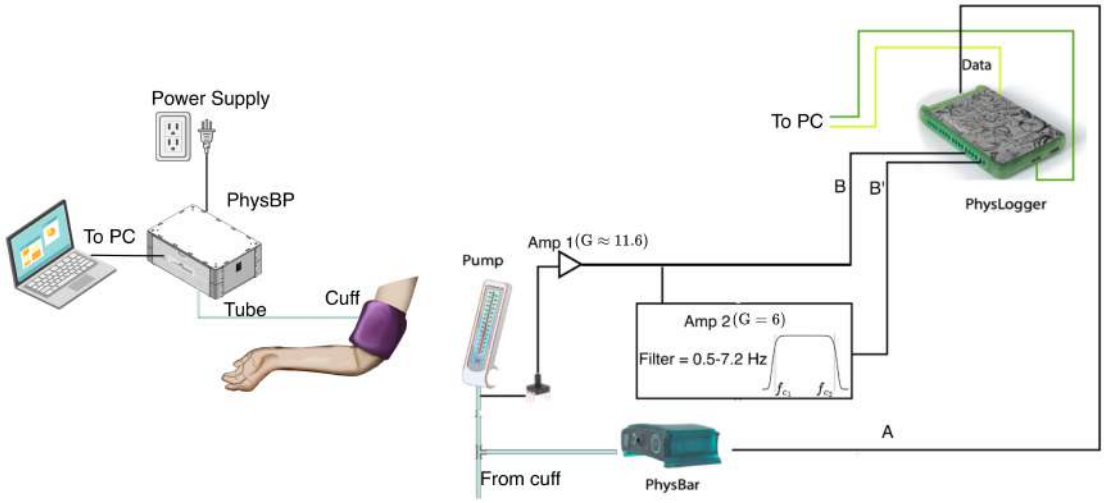


Figure 2: The picture above shows (left) general experiment setup and (right) schematic diagram shows the internal working of PhysBP. In the schematic diagram, A is the cuff pressure from PhysBar, B is the output from PSG010 sensor and B′ is the filtered signal.

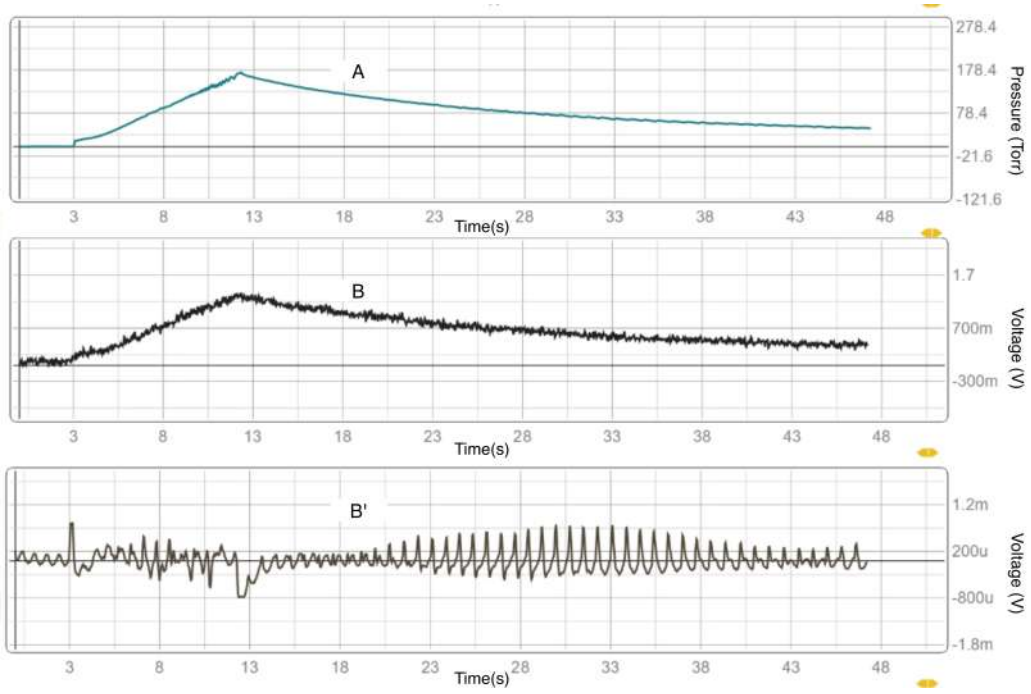


Figure 3: The graphs shows: (A) cuff pressure read by PhysBar, (B) output from PSG010 sensor in the form of voltage and (B′) filtered output from PSG010 sneosr in voltage.

The other sensor is a PSG010. This sensor produces a voltage B proportional to the pressure. The output from PSG010 passes through a sequence of filters that passes signals in the 0.5–7.2 Hz range produces a gain of $G \approx 70$ can be seen in Fig.3 (bottom). The complete circuit diagram can also be seen on the website. The output before filtration and amplification can be seen in Fig.3 (middle). Note that this is in voltage units. Therefore, in order to convert this unfilltered, unamplified voltage into pressure, we can compare the pressure A read from PhysBar and the voltage B, that is produced by the PSG010 path, and deduce a calibration factor for this path.

Remember that the pulsatile flow of blood in the artery is compressing and decompressing the air in the cuff which deflating after reaching a certain pressure. The overall pressure measurement during the deflate cycle will therefore look like a slowly decreasing quantity with tiny oscillations riding.

In order to analyze these tiny oscillations riding on top of our signal, we pass the signal through a combination of low-pass and high-pass filters. The band-pass filter comprises of electronic components that allow frequencies within a certain range to pass through while blocking the other frequencies. The filter picks out the allowed frequency oscillation part from the slowly varying frequency cuff voltage range. These oscillations are then amplified and routed to PhysLogger.

Procedure:

Start by setting up the apparatus. Make sure everything is well-connected. Open the Physlogger Desktop software as shown in the Appendix.

Deflate the cuff to make sure there is no pressure build-up. Now wrap the cuff tightly around your or your lab partner's arm above the elbow. Press the `Inflate` button and just relax and observe the beautiful oscillations appear on the screen.

Once you think you have recorded enough data, save it in a table. Now you can move onto processing this data in any programming language of your choosing.

Remember to properly deflate the cuff before each reading!

What does the data say?

[A]. The Fourier Transform

A very important tool we use to analyze digital signals is the Fourier Transform.

Biomedical signals are often composed of many different sinusoidal waves added together. These waves can be of different frequencies and amplitudes. The Fourier Transform takes your signal from the time domain and transforms it into the frequency domain, letting us to see the amplitude of different components.

This basically means it breaks the signal apart and shows you which individual frequencies are inside it. In Fig.6 and 5 you can see a simple picture of how this concept works.

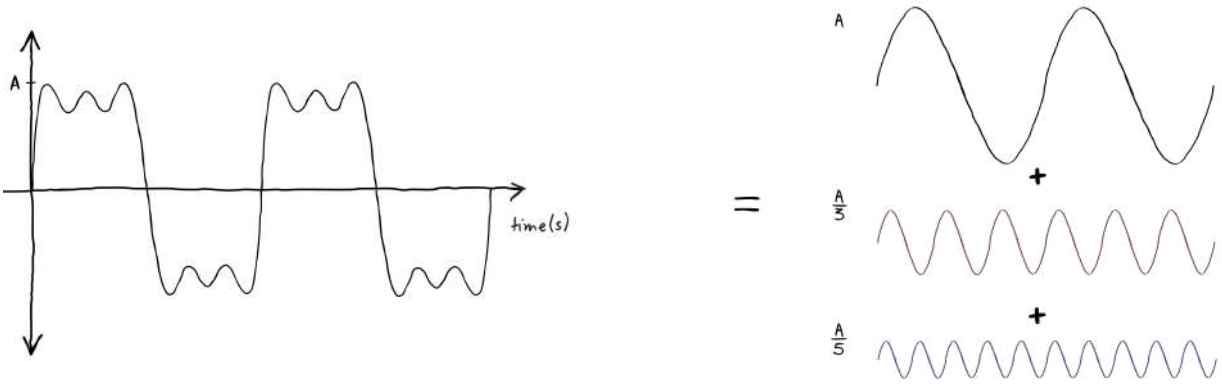


Figure 4: The signal on the left is made up of three sinusoidal waves of varying frequencies and amplitudes.

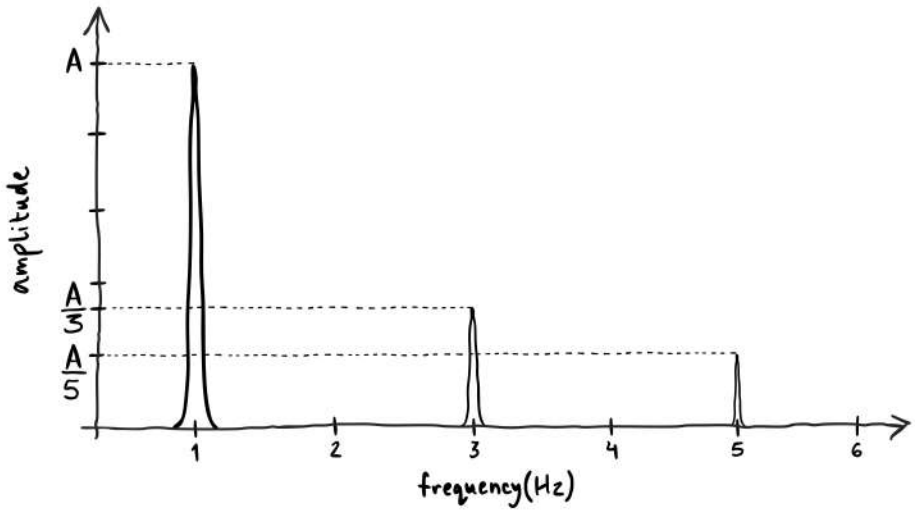


Figure 5: The Fourier transform has given us three peaks, each of which corresponds to the constituent wave which makes up our signal.

[**Q1**.] As you may now understand, these oscillations are made of many frequency components too. By implementing the Fourier Transform on your data, explore these components and understand what each one represents.

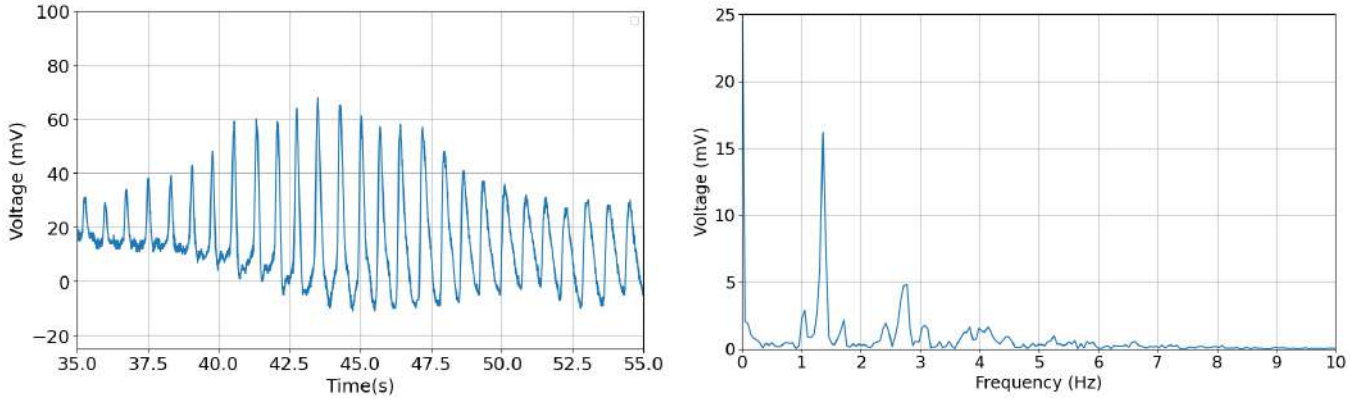


Figure 6: The graphs shows (left) is output from PSG010 sensor having different frequency components and (right) is the Fourier Transform of the signal showing constituent elements which makes up the signal.

[Q2.] Compare the data from PhsBar A and the PSG010 sensor B to calibrate the sensor B data into pressure. Find the calibration factor and convert voltage B into pressure B.
(Note the signal B is coming after first amplifier with gain $G \approx 11.6$.)

[Q3.] Use this information, (i.e the calibration factor from **Q2** as well as the gain 70 in the B′ channel) to mark the pressure readings in the oscillations, this converts the voltage B′ into pressure B′.
(Note the signal B′ is coming after amplification with gain $G \approx 70$.)

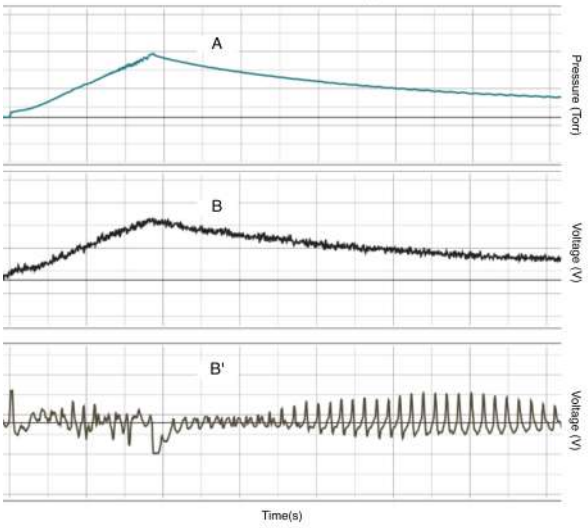


Figure 7: The graphs shows: (A) cuff pressure read by PhysBar, (B) output from PSG010 sensor in the form of voltage and (B′) amplified filtered output from PSG010 sneosr in voltage.

[Q4.] Now, when you have the oscillations data B′ in pressure form, you may notice that as the pressure inside the cuff increases the arterial oscillations starts disappearing. What could be the reason for that?
[Q5.] From this point onward, we are only concerned with the meaningful range when the cuff starts deflating. Slice the data to obtain meaningful range thus avoiding unwanted peaks.

[B]. The envelope

Another tool we often use in signal processing is called the envelope. It is a curve that outlines the variations in the amplitude of a signal.

[Q6.] Find the peaks in the data from experiment and create an envelope outline the oscillations in the signal.

To help you practice creating an envelope, extract data from your experiment and the Python code provided to you and available in the Appendix. First, you will find the peaks in the signal then spline fit those peaks to create an envelpe. This is just one of the many ways you can create an envelope.

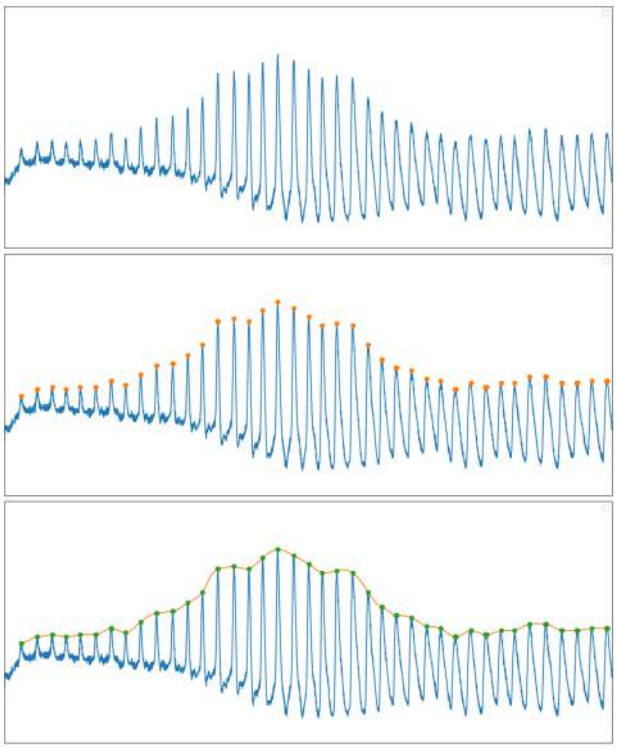


Figure 8: The graph illustrates the steps for envelope generation: (top) signal, (middle) peaks detected in the signal and (bottom) envelope created by spline fit over the detected peaks.

[**Q7**.] See where the envelope reaches the maximum peak of pressure. This will be an estimate of the mean arterial pressure (MAP).
[**Q8**.] Now, find where the amplitude first reaches 0.55 times the MAP before the maximum peak. This is known as systolic blood pressure (SBP).
[**Q9**.] Similarly, find where the amplitude first reaches 0.82 times the MAP after maximum peak. This is known as diastolic blood pressure (DBP).
[**Q10**.] Map the SBP and DBP with their respective cuff pressures. Can you estimate what was the blood pressure of the person from the data?
(Note: Make sure only the required peaks MAP, SBP and DBP are shown in the graph.)

[**Q11**.] Can you find the shape index of envelope within the meaningful range?
(Hint: Scale the SBP and DBP time values as 0 and 1 respectively, and try to estimate the corresponding MAP value.)

$$Shape\ index = \frac{T_{MAP} - T_{SBP}}{T_{DBP} - T_{SBP}}$$

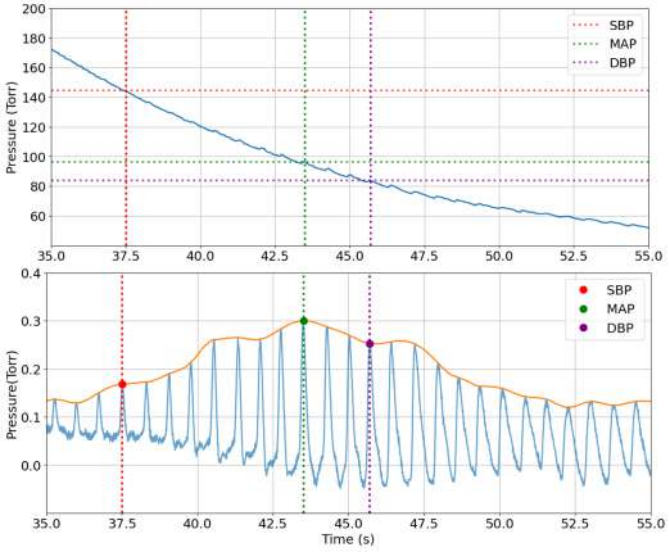


Figure 9: In the illustration: (top) is cuff pressure and (bottom) is arterial pressure. The MAP, SBP and DBP are clearly marked in the graph and their respective cuff pressures are mapped as well.

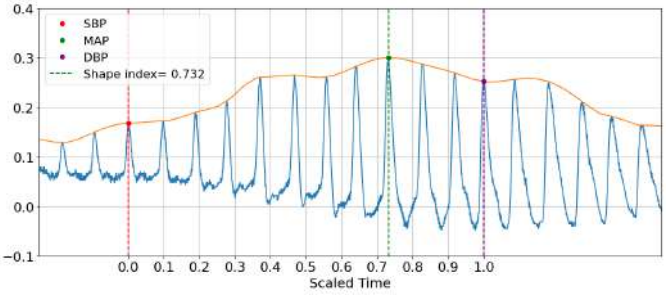


Figure 10: The shape index of envelope is shown in the graph by scaling the time axis.

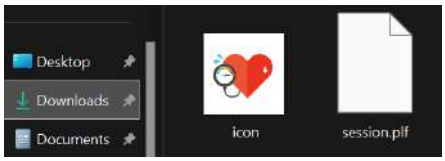
Appendix

```
# Following is the helping code to detect peaks in your data.
    # Step 1: Import all the essential libraries.

    from scipy.signal import find_peaks
    from scipy.interpolate import PchipInterpolator

    #Step 2: Find the peaks in your data.
    # adjusting the value of 'prominence' helps with peak identification
    peaks_idx, _ = find_peaks(voltage_hpf_v, prominence=0.2)
    pks_4 = voltage_hpf_v[peaks_idx]
    locs_4 = time_s[peaks_idx]

    # Step 3: Interpolate for the upper envelope using 'pchip'
    # 'extrapolate' allows the spline to cover the full range of time4
    interp_func = PchipInterpolator(locs_4, pks_4, extrapolate=True)
    up4 = interp_func(time_s)

    #Step 4: Plot everything.
    plt.figure(figsize=(30, 6))
    plt.plot(time_s, voltage_hpf_v, label='Signal', alpha=0.7)
    plt.plot(time_s, up4, '-', label='Envelope')
    plt.plot(locs_4, pks_4, 'o', label='Peaks')


    plt.title('Arterial oscillations with envelope')
    plt.ylabel('Voltage/V')
    plt.xlabel('Time/s')
    plt.legend()
    plt.grid(True)
    plt.show()

```

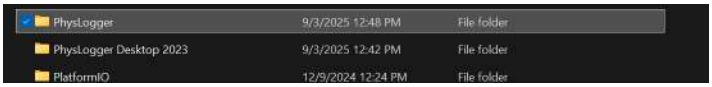
```
# Following is the helping code to apply Fourier Transform on your data.

    #Step 1: Set the sampling rate same as the rate at which you have taken the
    data.
    sampling_rate = 100

    # Step 2: Perform FFT on selected signal
    N = len(voltage_v) # Let the signal is voltage_v
    fft_result = np.fft.fft(voltage_v)
    freq = np.fft.fftfreq(N, d=1/sampling_rate)
    mag = np.abs(fft)

    #Step 3: Keep only positive frequency components.
    pos_freq_idx = freq >=0
    freq = freq[pos_freq_idx]
    mag = mag[pos_freq_idx]

    #Step 4: Plot the frequency components
    plt.figure(figsize=(10, 6))
    plt.plot(freq, mag)
    plt.title('Fourier Transform on Signal')
    plt.ylabel('Voltage (mV)')
    plt.xlabel('Frequency (Hz)')
    plt.grid(True)
    plt.show()

```

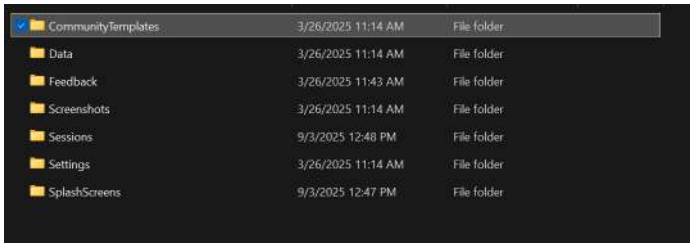
1. Download the ***Physlogger*** app from ***https://qosainscientific.com/physlogger-desktop/***

2. From the community template section of the above given website, download the ***PhysBP template***. You will have two such files downloaded. Copy these files.

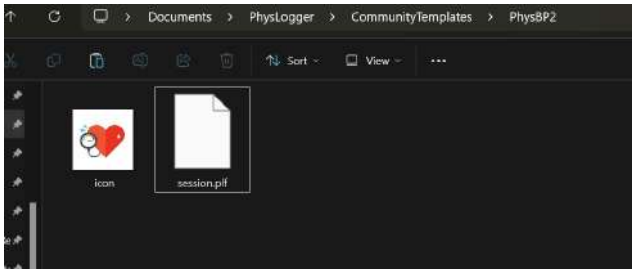


3. Go to ***Physlogger*** in *Documents*, and then open the ***CommunityTemplates*** folder.



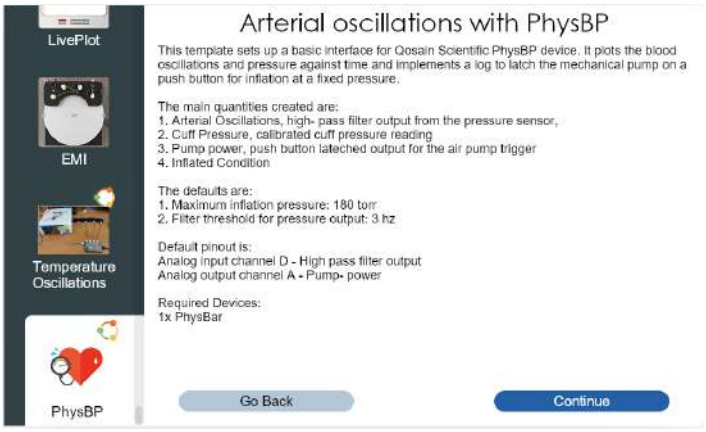


4. Paste the two files in ***CommunityTemplates***.

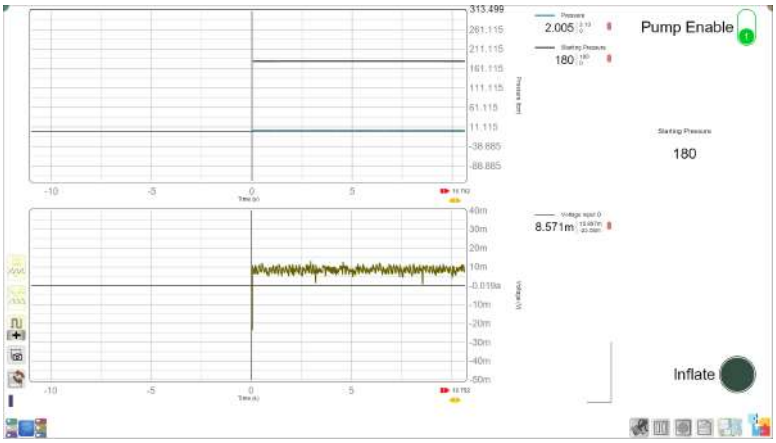


5. Open the ***Physlogger App*** from *Desktop*. Select ***Explore***.

6. Select ***PhyBP's*** icon and click continue.

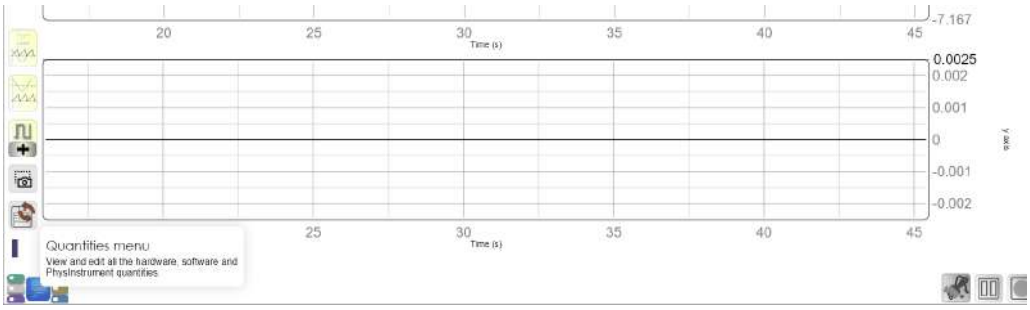


7. An interface like this will open. You can see that it includes a pump and two live plots for pressure and voltage readings.



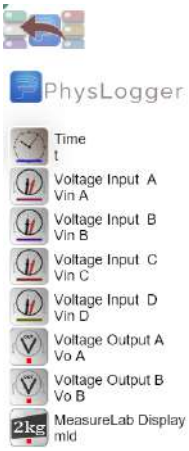
8. To include a third live plot for the raw voltage, click the highlighted icon. It will create an empty plot.

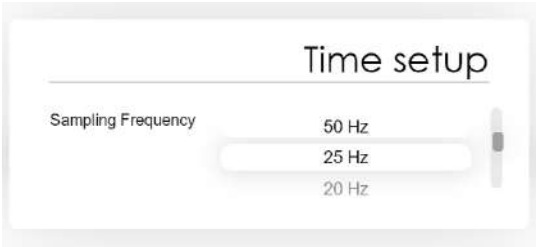
10. Click the ***Quantities*** icon and drag and drop your desired quantity to the y-axis of the plot.



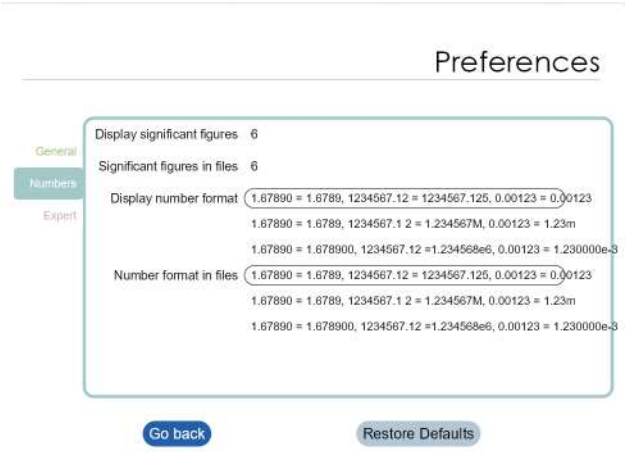
11. For this experiment, you can set the sampling frequency to 25Hz. This is not compulsory and you can certainly go above this value, but a low sampling rate reduces the noise in your data.

To do so, click the quantities icon and select the quantity ***Time***. There you can choose an appropriate sampling rate.





12. You can also change the format of the numbers displayed and saved by clicking on the ***Options*** icon on the top right.



13. To start the pump, make sure the pump icon is set to enabled. Then just click ***Inflate***.

References

[1] World Health Organization, *"Hypertension Pakistan 2023 country profile"*, (2023), https://www.who.int/publications/m/item/hypertension-pak-2023-country-profile.

[2] Wellcome Collection, *"Stephen Hales measuring blood pressure in a horse "*, Available at: https://wellcomecollection.org/works/km4x3rye/images?id=mksytnwg.

[3] P.S. Lewis, *"Oscillometric measurement of blood pressure: a simplified explanation. A technical note on behalf of the British and Irish Hypertension Society"*, Journal of Human Hypertension **33**, 349–351 (2019).

[4] C.D. Bertram, *"Flow phenomena in floppy tubes"*, Contemporary Physics **45**:1, 45–60 (2004), http://dx.doi.org/10.1080/00107510310001639878.

[5] B. Lee, J. H. Jeong, J. Hong, et al., "Correlation analysis of human upper arm parameters to oscillometric signal in automatic blood pressure measurement," *Scientific Reports*, vol. 12, Article 19763, 2022. doi:10.1038/s41598-022-24264-9.