Arterial oscillations in blood pressure measurement

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Blood pressure measurement is a common household technique. Given the indispensable importance of using blood pressure as a marker of disease, the market is inundated with low-cost measurement gadgets. The time-tested technique involves wrapping a cuff around the upper arm, right above the elbow, and pumping air into the cuff until it reaches an appreciable pressure around ≈ 200 to 250 mm Hg. At the same time, a stethoscope is tucked under the cuff and the nurse or doctor patiently hears through the earpieces. The extra pressure in the cuff occludes the brachial artery, preventing any blood flow. As the pressure is slowly released through a venting valve, a point reaches when the cuff pressure just matches the pressure of the incoming bloodstream. This is called the systolic point. At this juncture, blood gushes through the artery and gives rises to a characteristic *Korotkoff* sound. A series of sounds is subsequently produced as the pumping heart causes pulses of blood to flow through the artery. Finally, when the cuff pressure has diminished to a point where the cuff loosens out of the arm, called the diastolic point, the Korotkoff sounds disappear. This period of audible diagnosis is often called *auscultation*. The nurse notes down the starting and end points of auscultation and quotes this as your blood pressure, 125/82, for example.

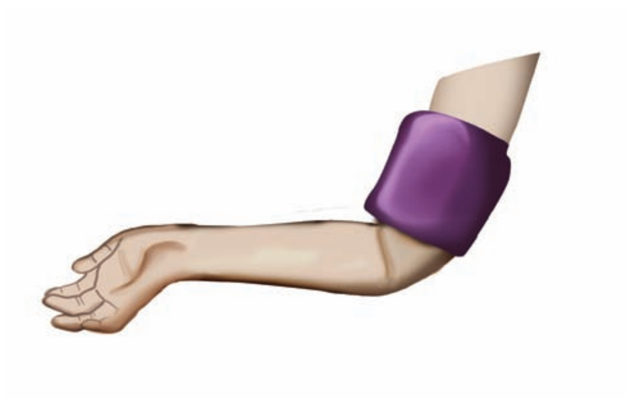

Figure 1: Cuff wrapped around the upper arm.

Modern measurement devices, especially the ones used in homes these days, however, don't require hearing out any audible signals and do away with the stethoscope. These devices, though approximate and require external validation, are very simple to operate. They are called oscillometric blood pressure measurement instruments. The track oscillations of the artery itself. In the period between the systole and diastole, the pulsating blood flow periodically fills and empties the artery. The artery, remember, is elastic and can expand or compress in response to blood flow. This subsequently compresses and decompresses the air in the cuff. If one were to directly measure the air pressure in the cuff with the help of some reliable solid-state transducer, the measurements would approximately follow the blood flow through the artery, and the readings would correspond to the pressure measurement of the pulsating blood flow. The overall pressure measurement would therefore look like a slowly decreasing quantity (due to the cuff being deflated) with tiny oscillations riding on top of it. Typical measurements are shown and described in Fig. 2.

In the present experiment, we intend to look at these tiny arterial oscillations and get a sense of how blood pressure measure can be measured. For this purpose, we have already created a pretty circuit for you. A schematic view is shown in Fig. 3 and a description follows.

A pump inflates a cuff wrapped around the arm. A bleed valve slowly releases the pressure. The experiment uses two pressure sensors. One is the PSG010. This sensor produces a voltage proportional to the pressure. This voltage is low-pass filtered and amplified. We need low pass filtering to remove high frequency noise. Remember that the deflating cuff pressure signal varies slowly (in the mHz range). Furthermore, the oscillating pulse is also at the most

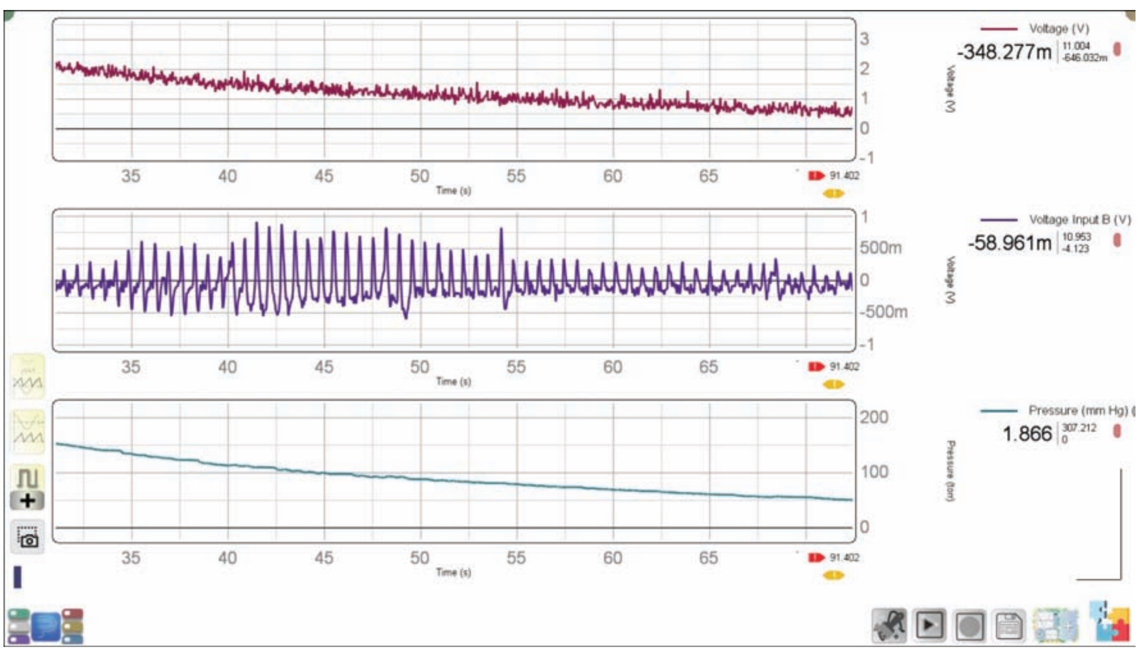

Figure 2: This diagram shows three plots. The top graph is the decreasing pressure in the cuff. Units are in volts because the pressure sensor takes in pressure and gives out a voltage. The middle graph shows the oscillations riding on top of the cuff pressure. These oscillations are extracted from the top data using a process called *high pass filtering*. Units are again in volts. The third measurement is taken from another pressure measuring device that we call the *PhysBar*. It is a calibrated sensor that directly gives readings in units of pressure such as mm Hg.

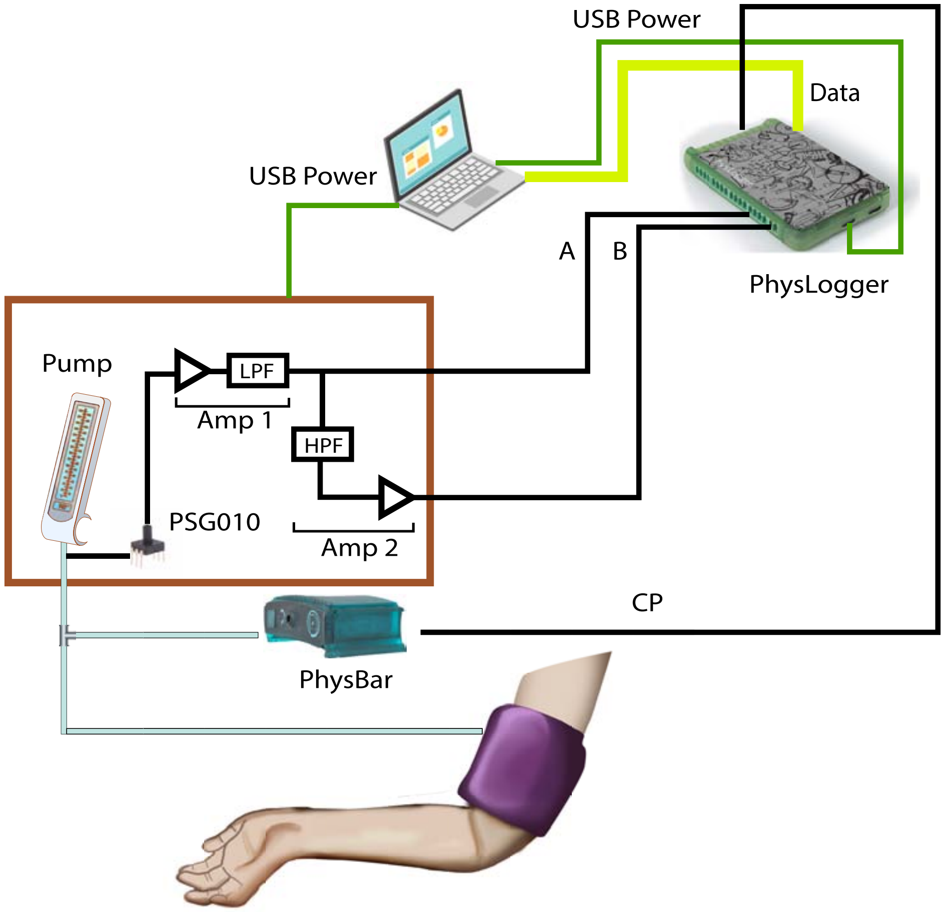

Figure 3: A schematic diagram of the experiment. Here are some abbreviations used in the diagram and the accompanying text: LPF=low pass filter, HPF=high pass filter, CP=cuff pressure, A and B and voltages from the cuff pressure and the oscillations respectively.

around 3–4 Hz (4 Hz=240 beats per minute!). So we can cut-out voltages above a certain frequency (in our case $\approx$ 20 Hz), taking away noise while preserving the signal of interest. This is called low-pass filtering. High-pass is the opposite!

The low-pass filtered and amplified voltage from the PSG010 is fed into channel A of a PhysLogger (http://www.physlogger.com) which helps the computer record and live plot the signal. This is the interface that you see in Fig. 2.

One part of this voltage, however, is high-pass filtered and is used to track the (relatively) higher frequency oscillation part, picking it out from the slowly varying frequency cuff voltage. These oscillations are amplified one more time and routed to PhysLogger's B channel and displayed.

For purposes of comparison, we have also used a pre-calibrated sensor fitted in a box that we call PhysBar. This pressure sensor is interfaced with a circuit that cleans the signal and produces a digital signal, called CP, also read by the PhysLogger. The output is directly displayed in pressure units (KPa or mm Hg) and can be used to calibrate channels A and B if you desire so.

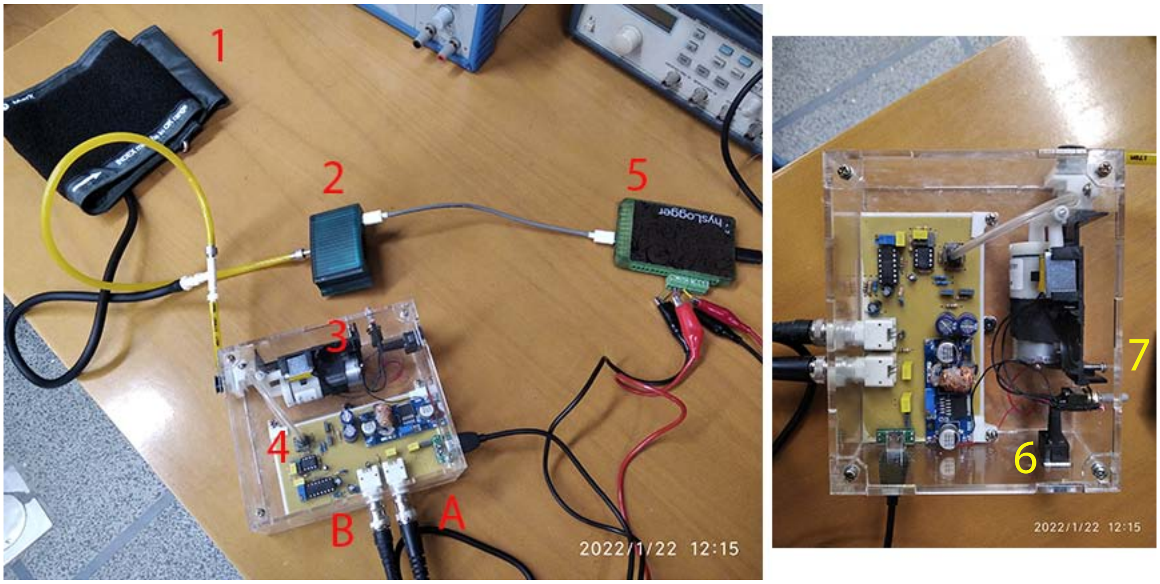

Figure 4: A photograph of the oscillation measurement device. The labels correspond to **1**=cuff, **2**=PhysBar, **3**=pump, **4**=PSG010 sensor, A and B have been described in the text, **5**=PhysLogger, **6**=power switch and **7**=toggle switch for inflation.

Wrap the cuff around your (or your co-worker's arm). Connect everything together (see Fig. 4 for seeing what the different parts are). Activate the box using the black switch on its side. The cuff can be inflated by pulling down on the toggle switch. When this switch is released, inflation stops and the bleed valve opens allowing a slow release. If at some point you want to rapidly deflate the cuff, simply turn the black switch to the off position.

Of course, you need to know how PhysLogger works and interfaces with various instruments. You can learn more about it from our websites (http://www.physlab.org/physlogger or http://www.physlogger.com) or ask a *friendly* instructor who can get you started. Here are a few suggestions of what you may like to do with this experiment. You will have to extract data, save it and reopen in a data processing software. Our favorite choice these days is Matlab.

Q 1. Observe the oscillations and mark an enevelope around the oscillations. See where the envelope reaches its maximum. This will be an estimate of the mean arterial pressure.
Q 2. Estimate where the envelope of oscillations reaches 30%, 30% or 50% of its peak. Either of these numbers could be a measure of the systolic pressure. In fact, there is no single consensus on what qualifies as the systolic pressure and different manufacturers come up with empirical algorithms to make their estimations. You never know what algorithm a commercial blood pressure measurement device uses to extract the systolic and diastolic pressures. However, we highly encourage you to see the brief note published in the Journal of Human Hypertension [1] which beautifully sums up how the main idea of the oscillometric method.

Q 3. Estimate the diastolic pressure. Perhaps you could consider this to be when the envelope drops to 70% of its peak value.

Q 4. Can you attempt to measure the following: (a) rate of deflation of the cuff, (b) converting the voltage reading from the PSG010 sensor into pressure in mm Hg?

Matlab command	Use
`sgolayfilt`	Savitzky-Golay filtering smooths a waveform, and reduces high frequency noise.
`findpeaks`	Finds maxima of a waveform. This can be useful for determining the envelope of the pulse pressure. Do consider the paramater '`MinpeakProminence`' that helps choose a threshold for peak identification.
`fft`	Finds the Fourier transform of a waveform.
`lsqcurvefit`	Used to curve fit data to pre-specified model.

Table 1: Some useful Matlab commands.

Q 5. What frequency components exist in the arterial oscillations? Generally we determine this by implementing the Fourier transform.

In Table 1 we list some useful Matlab commands that can help you in answering some of these questions.

References

[1] 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).