USC University of Southern California

EE 105: Introduction to Electrical Engineering

Lab 3.2

Pulse oximeter and PPG

Yasser Khan

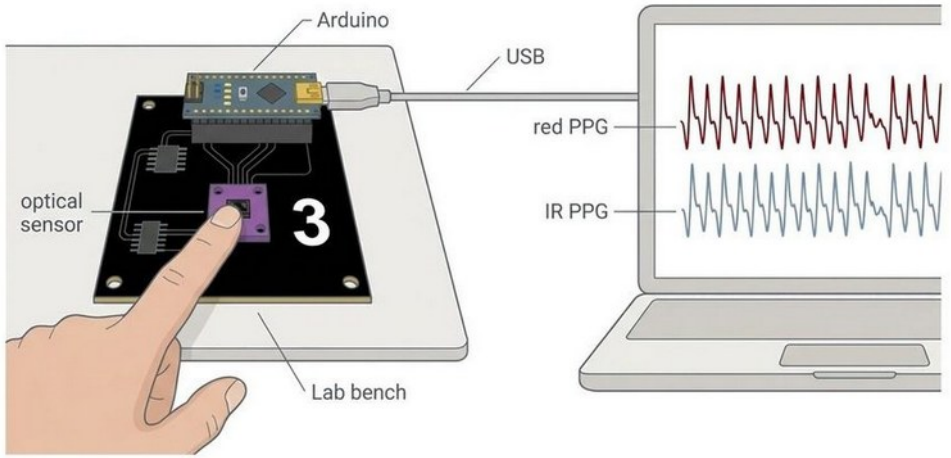
Rehan Kapadia

Today's mission

Shine red and infrared light into your fingertip and read your heart rate and blood oxygen.

By the end of this lab you can:

- Record red and infrared **PPG** signals from your fingertip
- **Filter** the signals and find every heartbeat
- Compute your **heart rate** two ways: peaks and FFT
- Estimate **SpO2** from the ratio of ratios



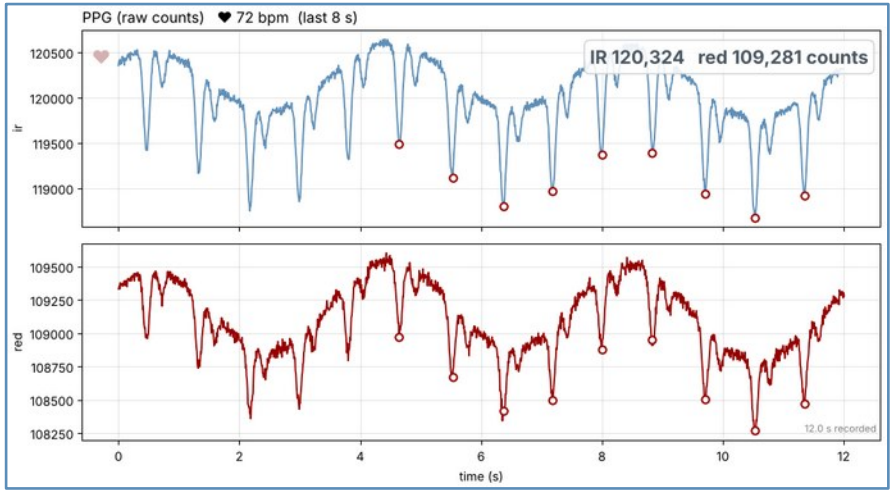
Rest a fingertip on the sensor; both colors show your pulse.

A	B	C	D	E	F
Connect	Live PPG	Record	Heart rate	SpO2	Experiment
5 min	**10 min**	**15 min**	**35 min**	**25 min**	**25 min**

Key takeaways

What to remember from this lab, with the numbers that matter.

- **A PPG is mostly DC.** The pulsing part, AC/DC, is only 0.3 to 2 % in infrared and 0.13 to 0.8 % in red
- **Each heartbeat is a dip.** More blood absorbs more light; a 0.5 to 4 Hz band-pass filter keeps the pulse
- **Two methods, one heart rate.** Beat intervals and the tallest FFT line agree within 60/T, 2.4 bpm for 25 s
- **SpO2 comes from R,** the red AC/DC over the infrared AC/DC. A healthy finger: R near 0.4, about 100 %
- **A number is only as good as its signal.** With no finger the code still prints a heart rate



Expected result of B1 on the simulated board: both colors dip once per beat.

SETUP

Selector on the biosensing block and one jumper cap.



1. **S10 → Module 3**
   Turn the selector to Module 3, the biosensing block.

2. **J5 → P1-A**
   Cap on pins 1-2 of the small header printed P1-A-P2.

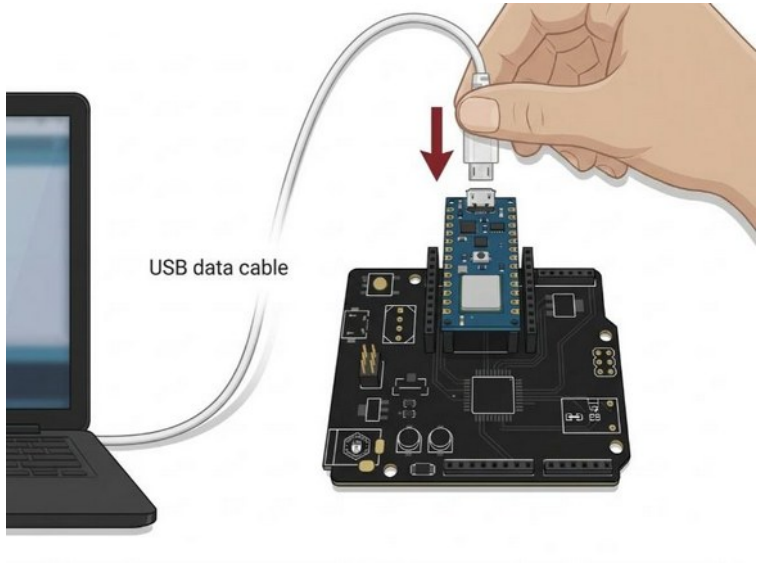
3. **Plugged in: nothing**
   This lab only uses the optical PPG sensor.

4. **USB data cable**
   Plug in last, then run the first cell.

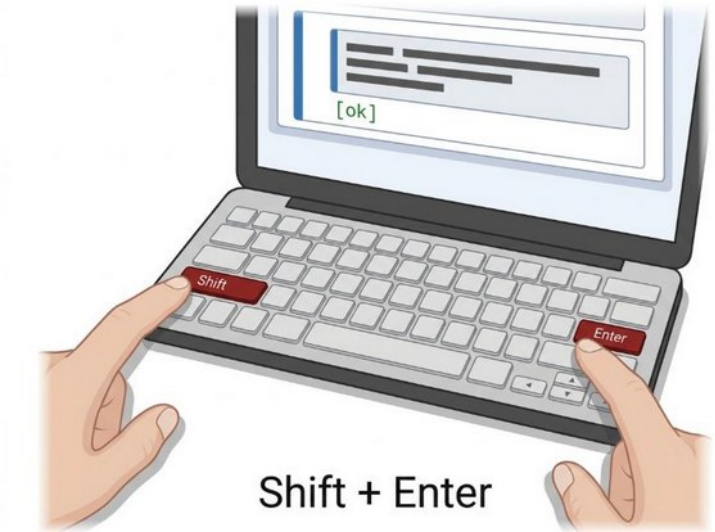
Part A: Connect

Plug in and run the first cell. No board today? SIMULATE = True practices on a simulated one.

PART A **Goal: A1 · DO** connect to the board and check the selector.



1 Plug the USB data cable into the Nano



2 Run cell A1 with Shift+Enter

You should see: both lines start with **[ok]** (firmware ee105). A **[!!]** line about the selector is only a warning: if S10 points at Module 3, carry on.

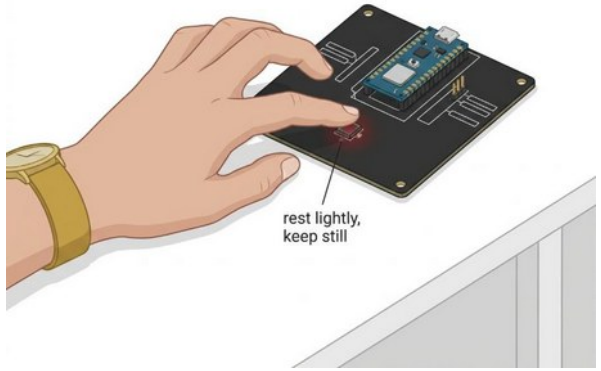
Part B: Live PPG

The sensor pulses a red (660 nm) and an infrared (940 nm) LED and measures the light that returns.

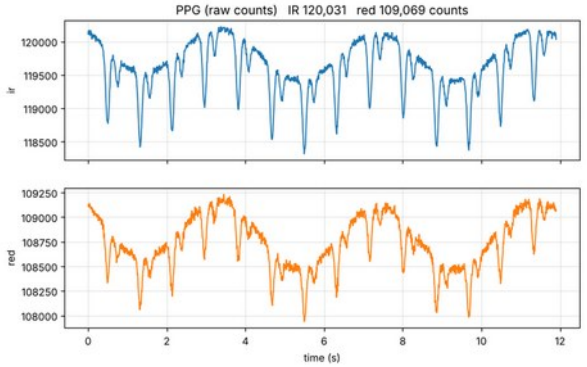
PART B

Goal: see your pulse live in both channels.

- **B1 · DO** Fingertip **ON** the sensor window, lightly. Do not press
- Forearm on the table, keep still; cup your other hand over the finger
- Run B1 (12 s live plot) with your finger, then once with no finger



Fingertip ON the sensor, resting lightly



Typical: one dip per beat

You should see: a sharp dip with each heartbeat in both traces; with a finger about **100,000 to 120,000** counts in each channel.

Check (Checkpoint 1): both live traces respond to your finger and show a clear pulse.

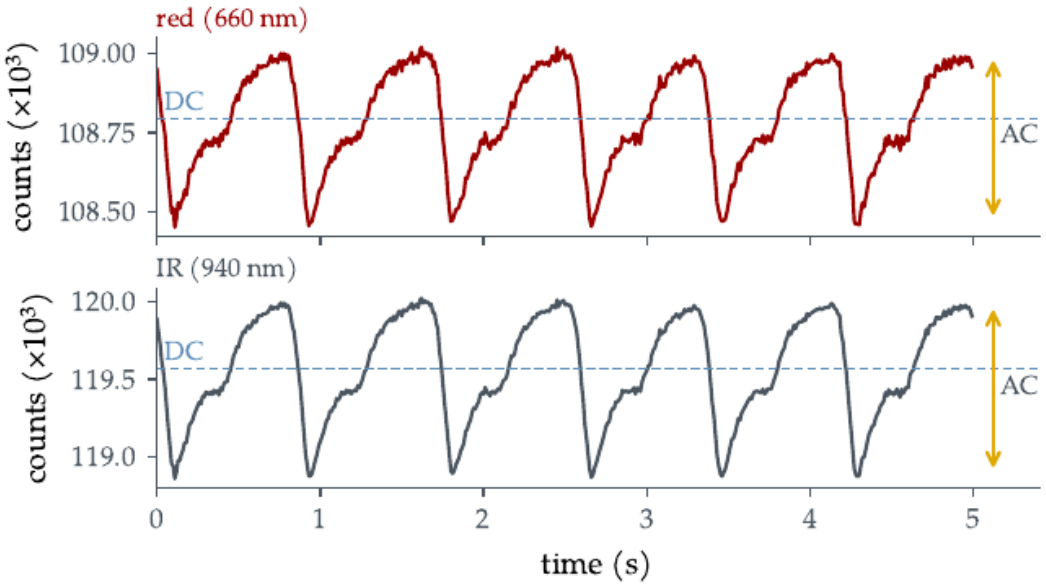
Part C: Record the raw data

25 s of both channels: a large steady DC level and a small AC dip with every beat.

PART C

Goal: record 25 s and find the sample rate and the DC levels.

- **C1 · DO** Record 25 s (**board.ppg**); keep still. Saved as **ppg_rest.csv**
- **C2 · EDIT** Sample rate fs from the time column; DC = mean of each channel
- **C3 · ANSWER** AC swing of each color, read off the plot



DC is the steady level, AC the swing of each beat.

You should see: 120 to 135 samples/s: the 3,250 samples take 24 to 27 s. AC/DC: IR **0.3 to 2 %**, red **0.13 to 0.8 %**. IR always larger.

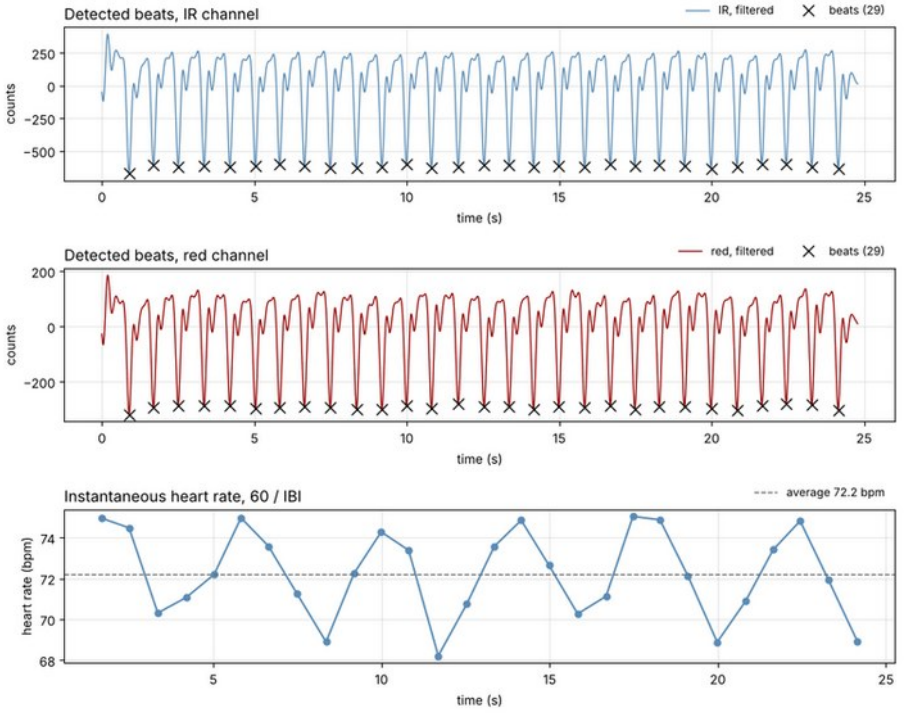
Part D: Beats and heart rate

A band-pass filter keeps the pulse; the dips mark the beats; the FFT finds the rate.

PART D

Goal: filter, find every beat, and compute the heart rate two ways.

- **D1 · EDIT** Band-pass **0.5 to 4 Hz**: detrend, **butter**, **sosfiltfilt**
- **D3 · EDIT find_peaks(-y)**: distance 0.4 s, prominence 0.3 of the swing
- **D5 · EDIT** Tallest FFT line in 0.7 to 3.5 Hz, times 60
- **D2, D4, D6 · RUN** Filter plots, beat marks, one-line rebuild



Typical: one mark under every dip, in both channels.

You should see: 50 to 90 bpm at rest; peaks and FFT agree within **60/T = 2.4 bpm** for a 25 s record. The backup file: **62.5 bpm** (peaks), **62.4** (FFT).

Check (Checkpoint 2): every beat marked in both channels; the two heart rates agree within the FFT bin spacing.

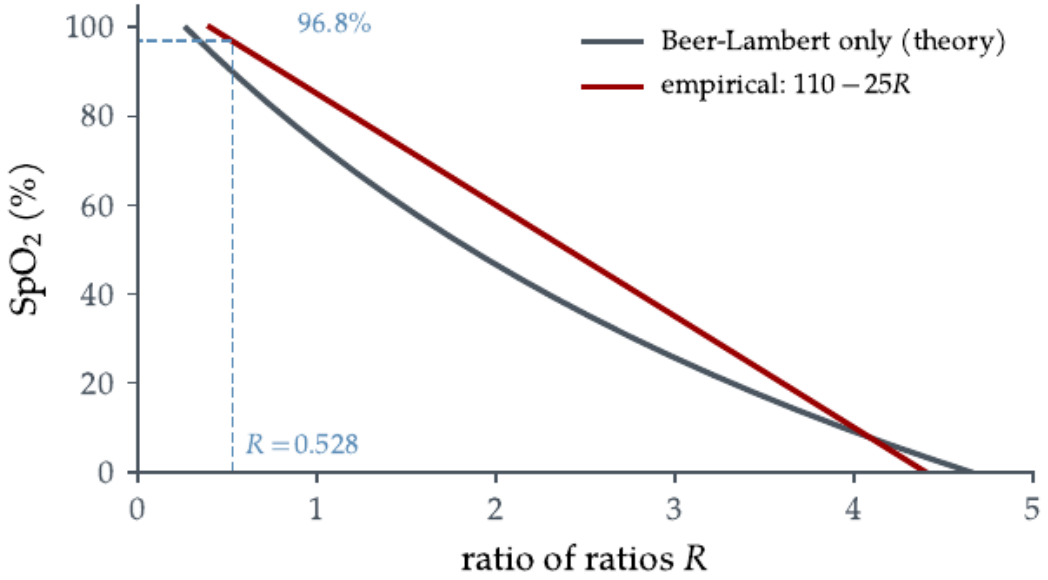
Part E: Ratio of ratios and SpO2

AC/DC per color, then their ratio R; the lab calibration turns R into SpO2.

PART E

Goal: measure AC and DC beat by beat and estimate SpO2.

- **E1 · EDIT ac_dc_per_beat**: AC = peak-to-peak of the filtered beat, DC = mean of the raw beat
- **E2 · EDIT** R for each beat, the median R, **SpO2 = 110 - 25 R**
- **E3, E4 · RUN** R plot; compare with **ppg_backup.csv**



The lab calibration 110 - 25R next to Beer-Lambert theory.

You should see: R about **0.36 to 0.45**, SpO2 about **99 to 101 %**. Above 100 % is the generic calibration, not your blood (Question 4).

Check (Checkpoint 3): four AC and DC values, R and SpO2, and one sentence on whether the result is physically reasonable.

Part F: What changes the PPG?

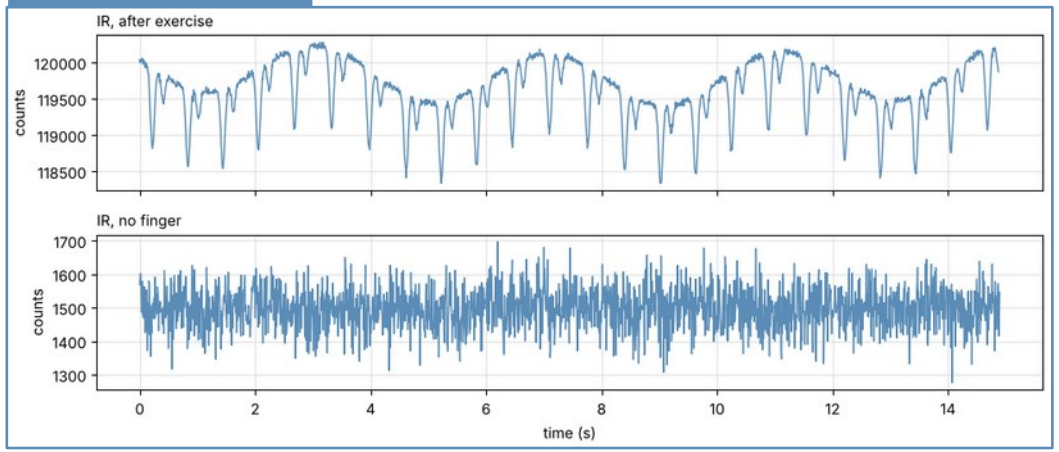
Record 15 s per condition with record_condition(name), then compare the table and plots.

PART F

Goal: see how pressure, no finger and (if you like) exercise change the signal.

- **F1 · RUN** Set up the recorder, once
- **F2 · DO "resting", "pressing hard", "barely touching", "no finger"**
- Optional: **"after exercise"** or **"holding breath"**, only if comfortable
- **F3 · RUN** Compare all conditions

Expected result · F3



You should see: pressing hard: AC/DC **falls**; no finger: DC drops to **a few thousand counts**, yet the code still prints a heart rate (Question 6).

Stuck?

Check these first. If the fix does not help, raise your hand.

No pulse, or a flat trace

Fingertip ON the sensor window, lightly: pressing hard squeezes the blood out.

A noisy, jumpy signal

Forearm on the table, no talking; cup a hand over the finger.

Counts stuck at 262,143, or wild jumps

Too much light: in C1, record with board.ppg(seconds=SECONDS, amplitude=0x40).

Beats missed, or extra marks

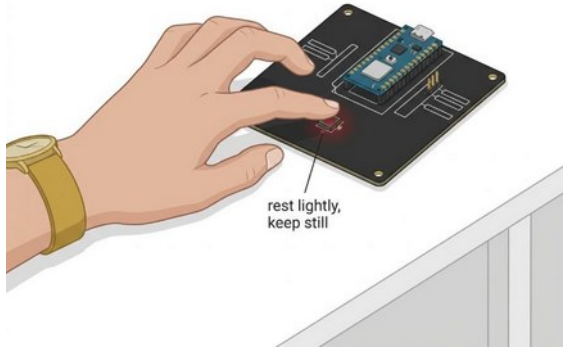
Adjust distance and prominence in find_beats (D3) and rerun.

A [!!] line about the selector

Only a warning. Check S10 on Module 3 and J5 on P1-A.

No clean pulse at all

USE_BACKUP = True in C1 analyzes ppg_backup.csv, a real recording.



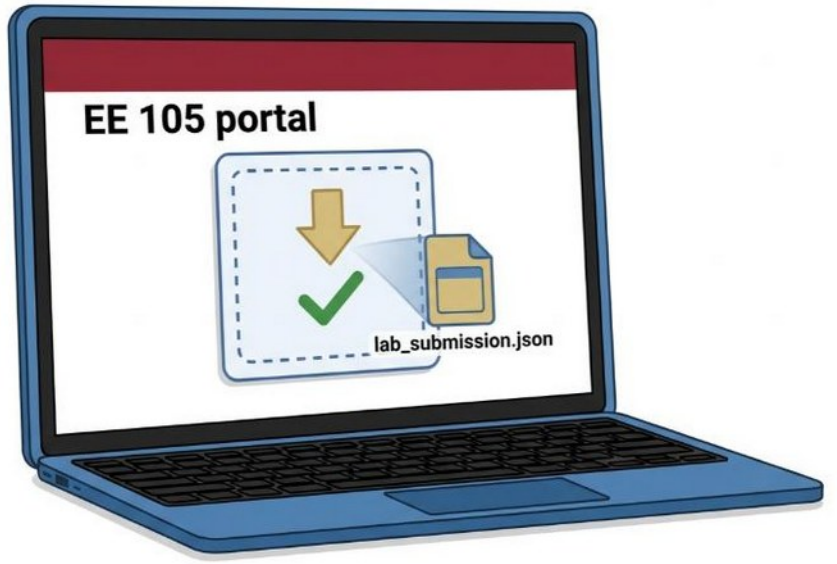
Fingertip ON the sensor window, light touch, other hand cupped over it.

Submit your results

The last cell saves your results in one file. Upload it on the course portal.

`lab3.2_submission.json`

1. **Save · RUN** writes **lab3.2_submission.json** next to the notebook
2. It holds your numbers, your Part C recording and the Part F summary
3. Log in at **ee105.org/portal** with your student ID and portal PIN; open Lab 3.2
4. Upload: the portal recomputes your heart rate from the recording



ee105.org/portal

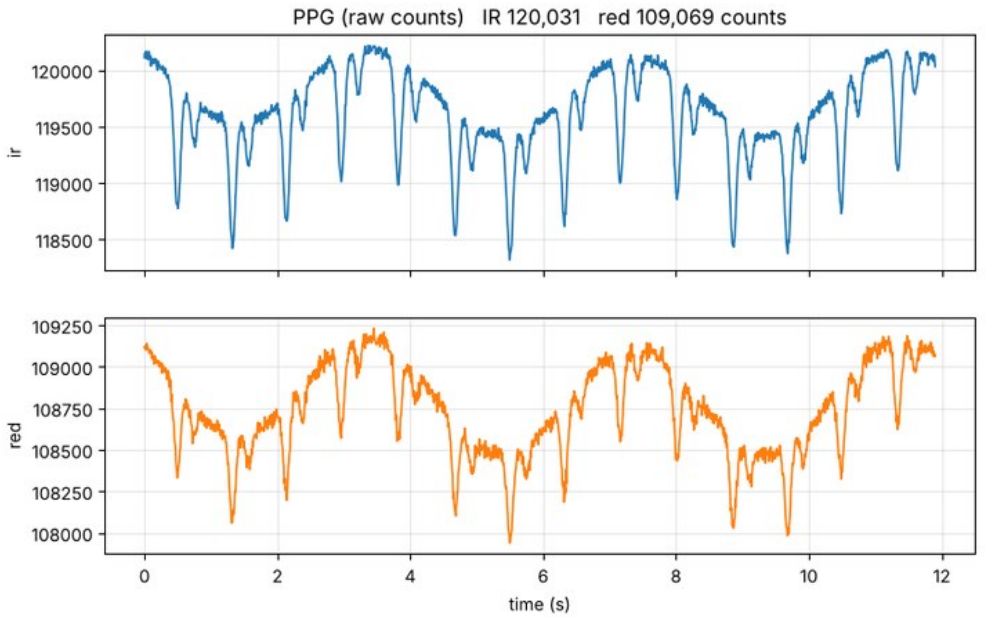
Check: the portal shows your grade. Your recordings stay in the lab folder as ppg_*.csv. A simulated run earns no credit.

Lab complete

You built a pulse oximeter: light in, heart rate and SpO2 out.

You built:

- A live two-color PPG from your own fingertip
- A filter and beat finder that marks every heartbeat
- Your heart rate from the peaks and from the FFT
- An SpO2 estimate from the ratio of ratios



Red and infrared PPG: one dip per heartbeat.

Did you know?

The same optical method runs on the back of a smartwatch: LEDs shine into the wrist and photodiodes a few millimeters away collect the light that scatters back (Chapter 3).

Next

Lab 4.1, neural networks: train networks that read handwritten digits. No board needed.