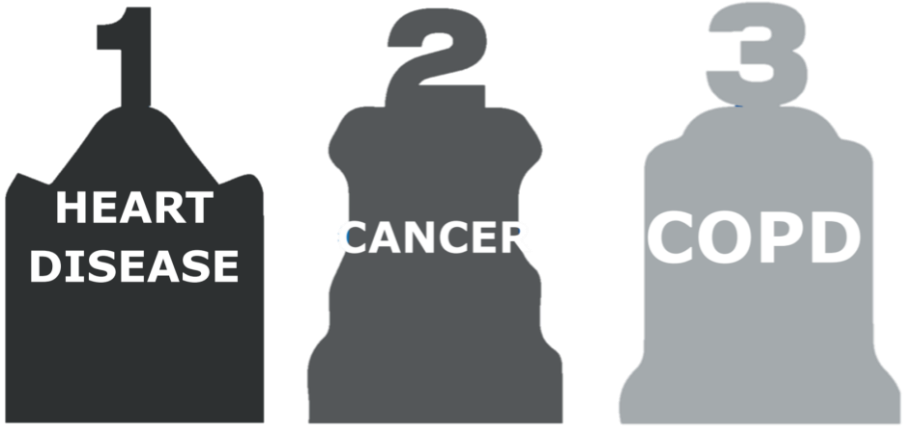
PhO$_2$

Smartphone based Blood Oxygen Level Measurement using Near-IR and RED Wave-guided Light

Nam Bui, Anh Nguyen, Phuc Nguyen, Hoang Truong, Ashwin Ashok, Thang Dinh, Robin Deterding, Tam Vu

Chronic Obstructive Pulmonary Disease (*COPD*)



Leading cause of death in the US, 2016

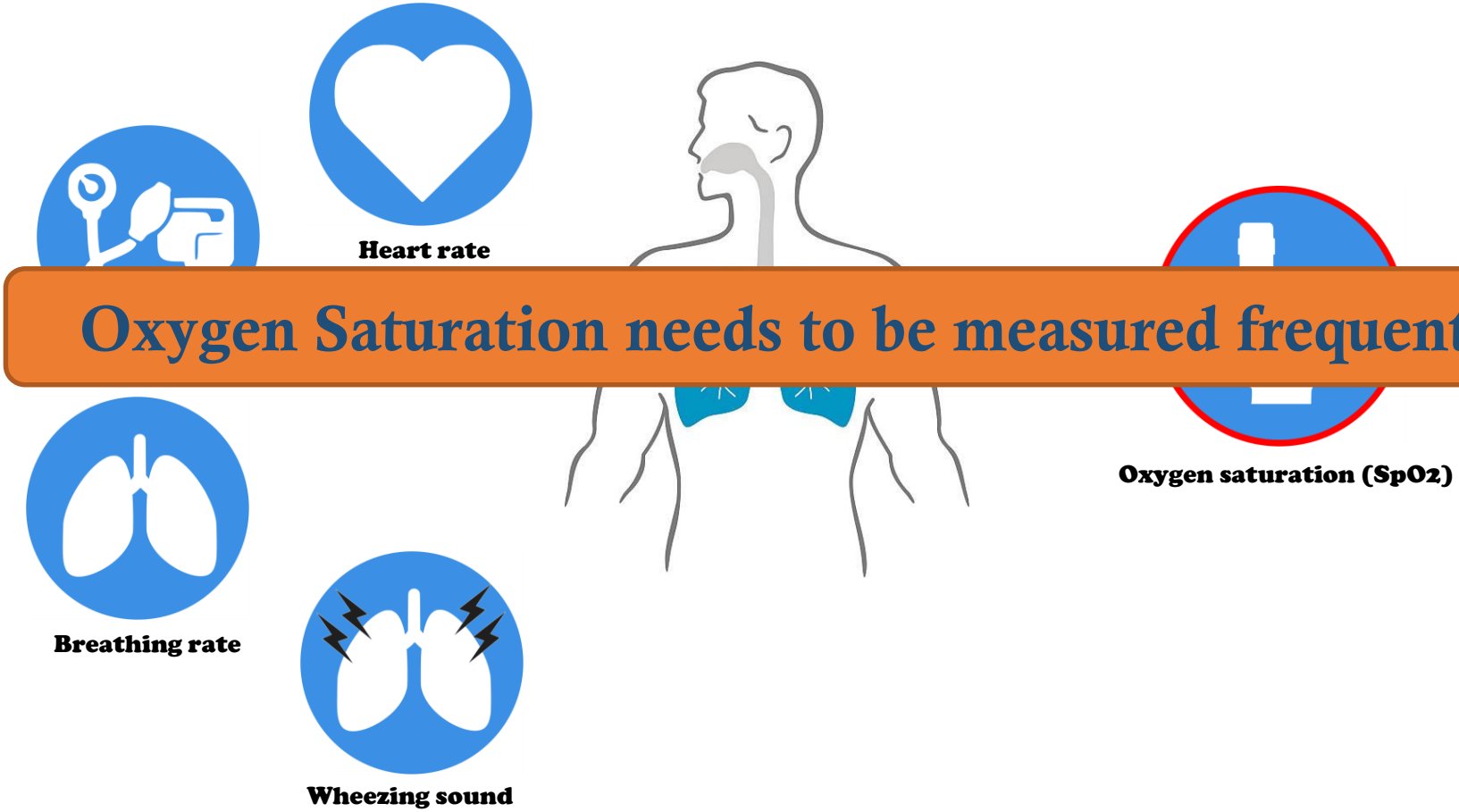
24 Million Americans have COPD

Early detection of COPD is key to successful treatment

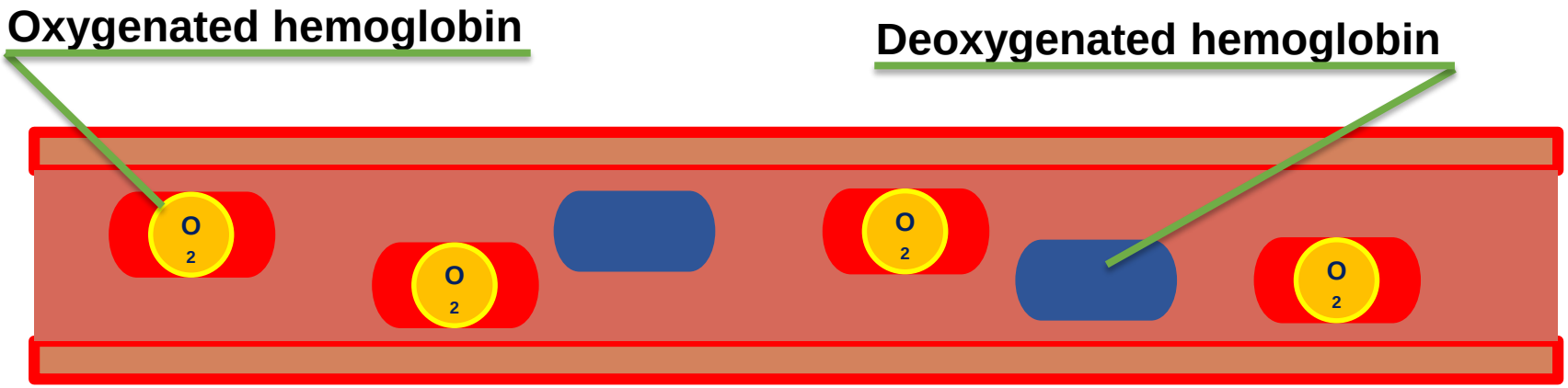
OFTEN
FOUND IN LATE STAGE

$34,000 treatment in ICU

Vital signs screening in COPD

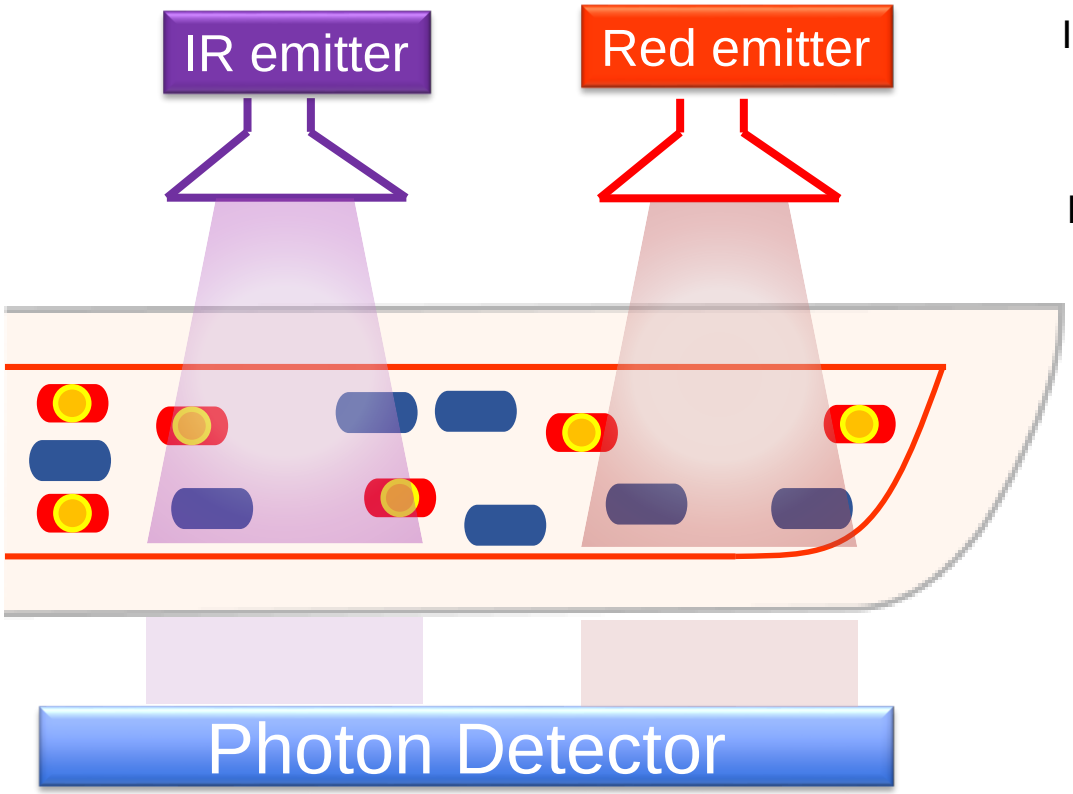


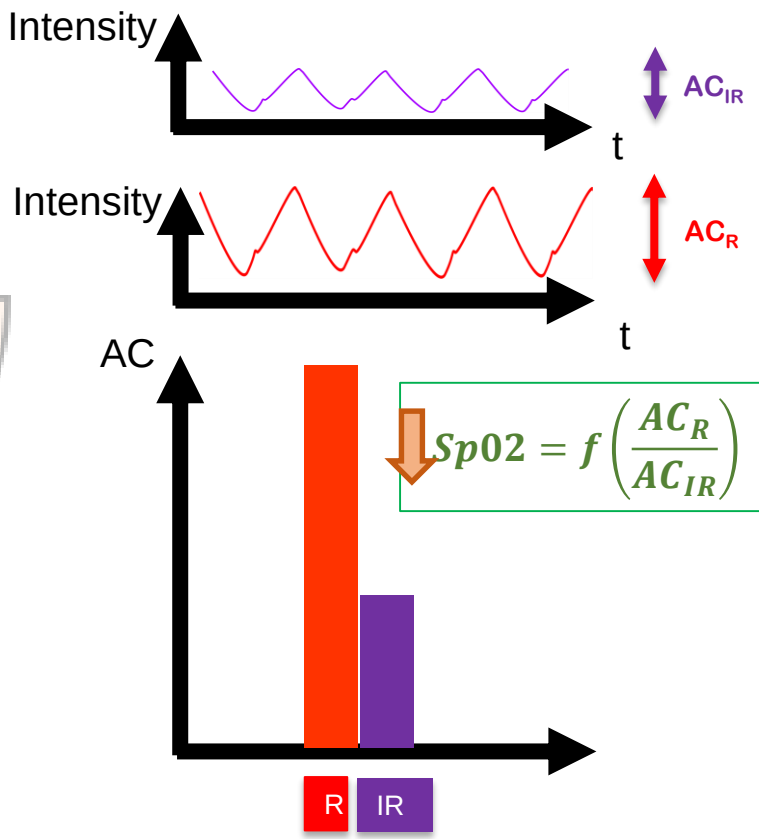
Oxygen Saturation (SpO_2)



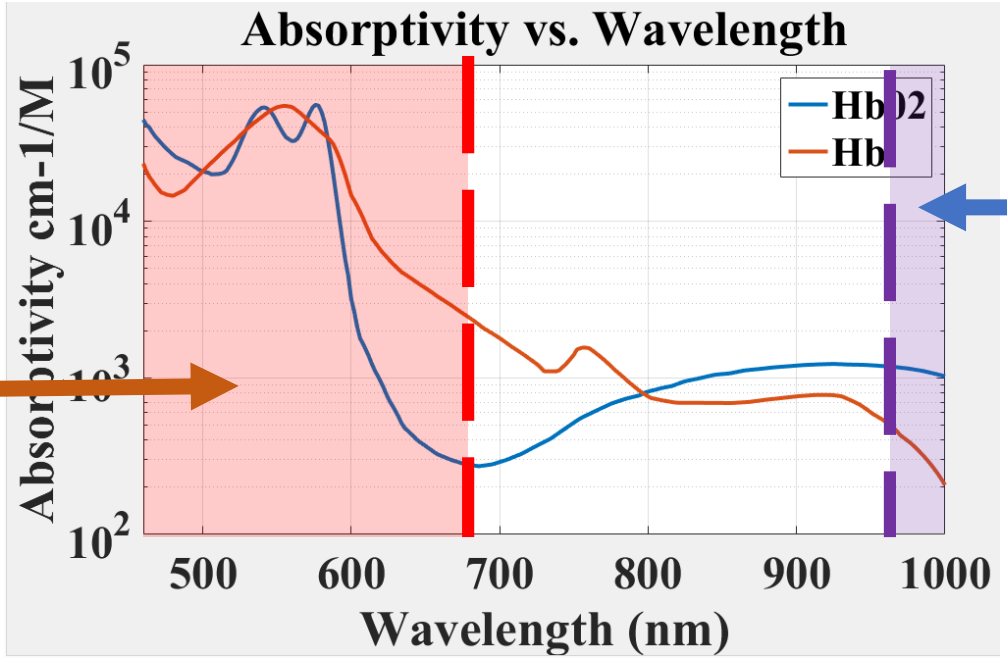
$$Sp02 = \frac{No.\,oxygenated\ hemoglobin}{Total\ No.\,hemoglobin} 100\%$$

Non-invasive Measurement of Oxygen Saturation





Red and IR Wavelength Selection



Absorbed by red pigmentation

Harmful
Low penetration

At **Red= 660 nm** and **IR = 960** nm, the difference of light absorption by oxygenated hemoglobin and deoxygenated hemoglobin is largest.

Dedicated Hardware Solutions

Smartphone-based blood oxygen measurement

Pros

- ❑ High accuracy

Cons

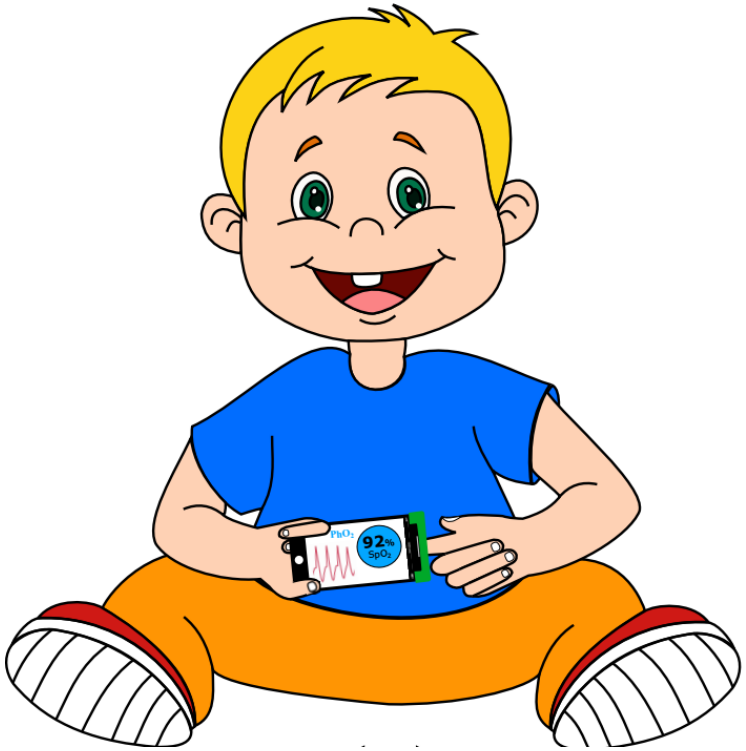
- ❑ Inconvenient
- ❑ Costly

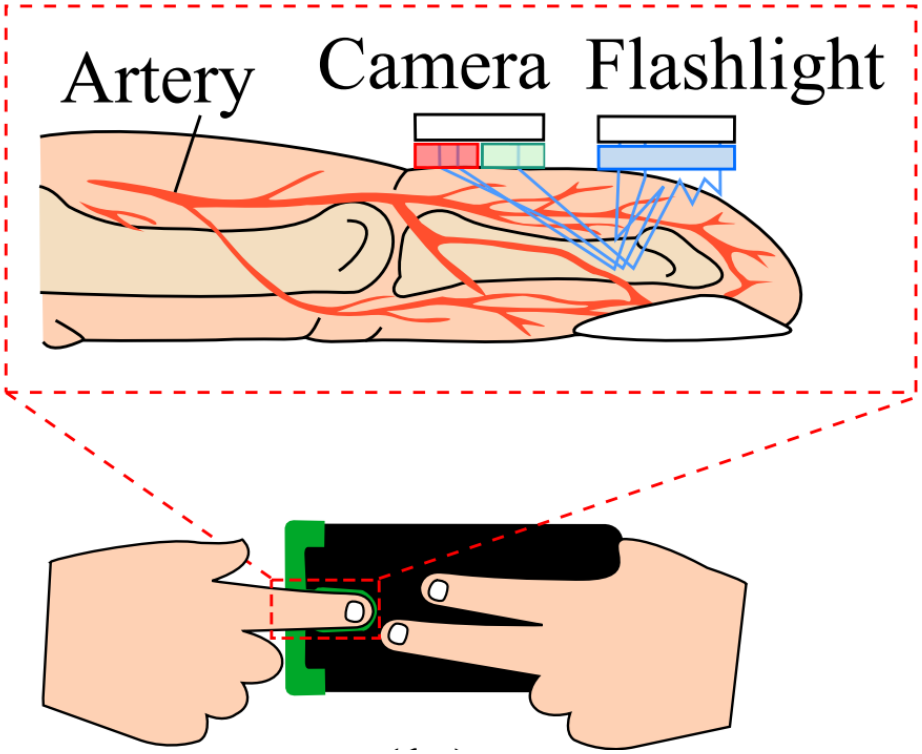
A solution to capture the oxygen level and is

- High accuracy.
- Low-cost.
- Easy to make by patients

PhO_2

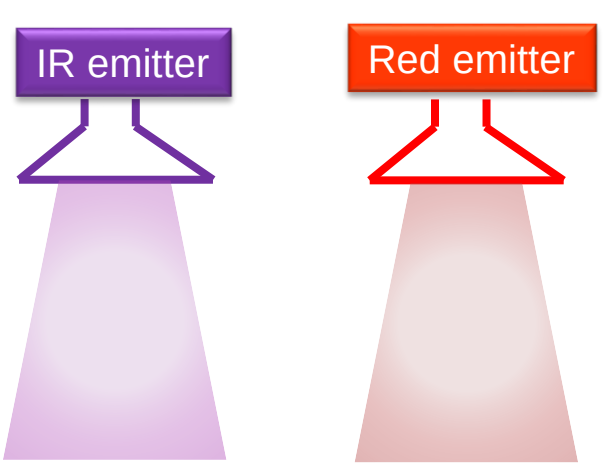
Smartphone based Blood Oxygen Level Measurement



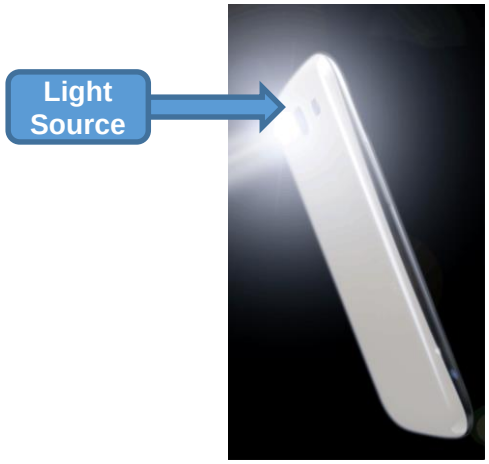


Hardware Challenges

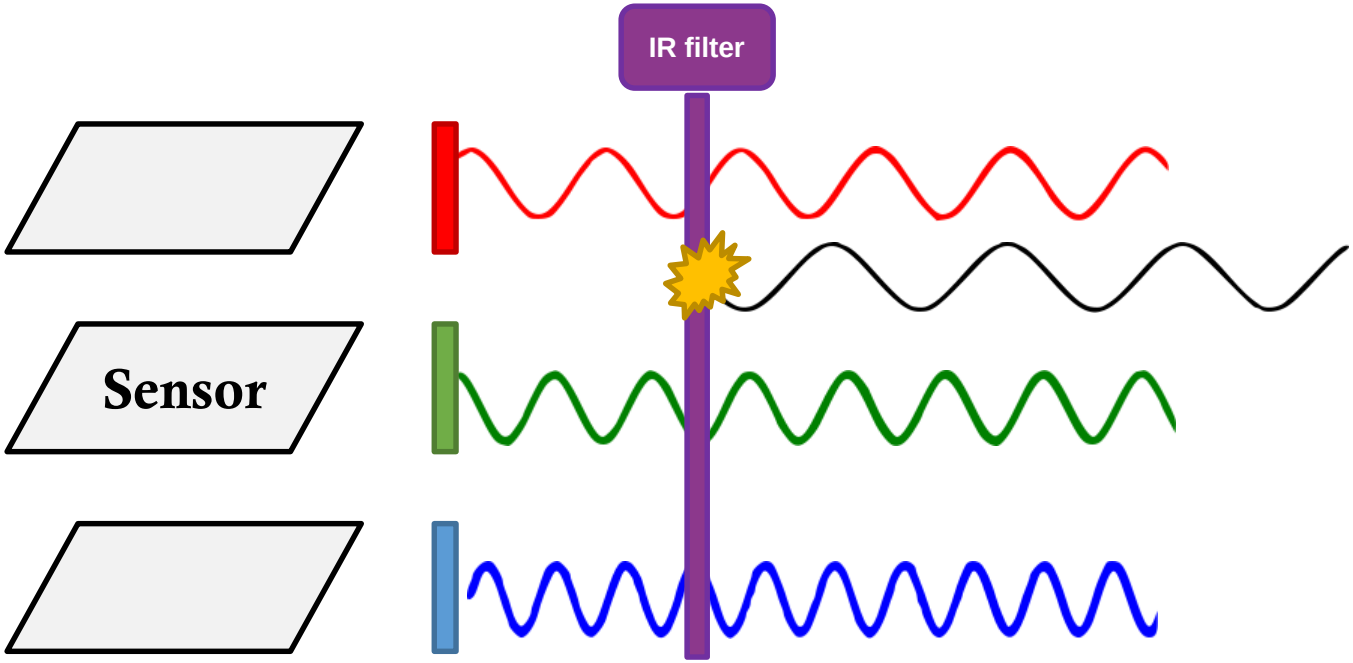
PULSE OXIMETER



PHONE BASED PULSE OXIMETER



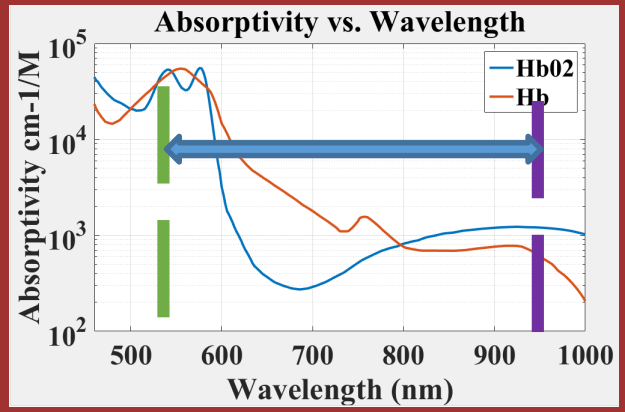
Challenge. Phone's camera IR filter



Existing Software-based Solutions

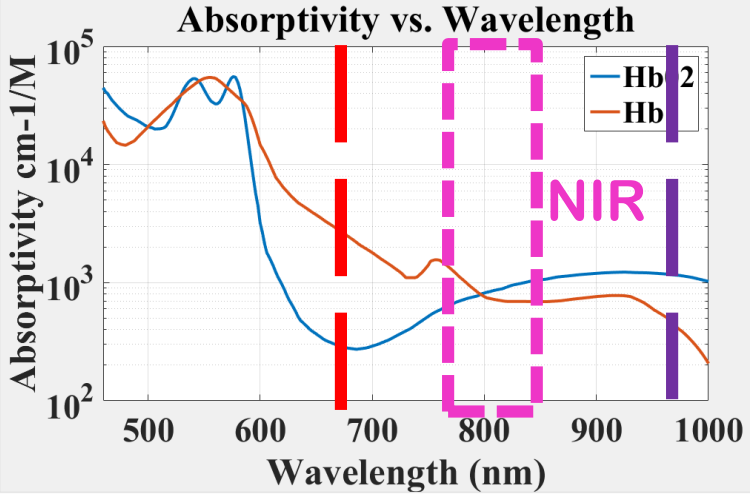
DISADVANTAGES

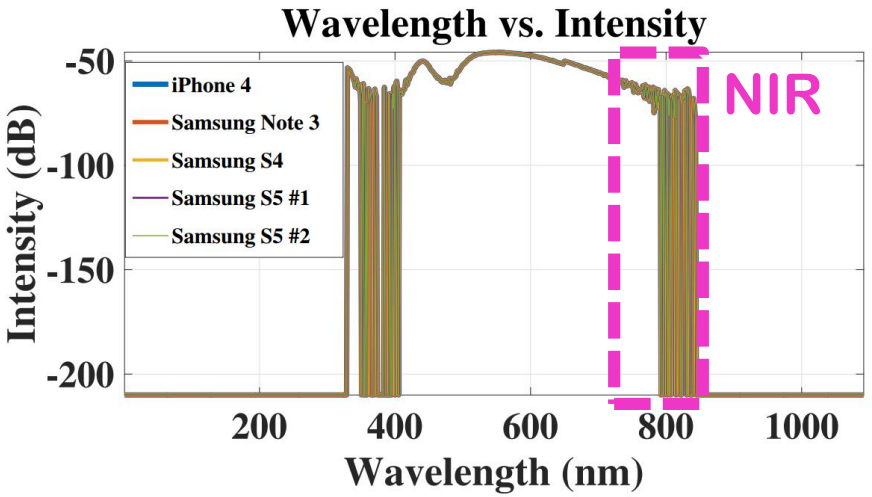
- ❑ Inaccurate: Green channel is mostly absorbed by red pigmentation.
- ❑ Coarse-grained: one record per 10 seconds.



Solution.

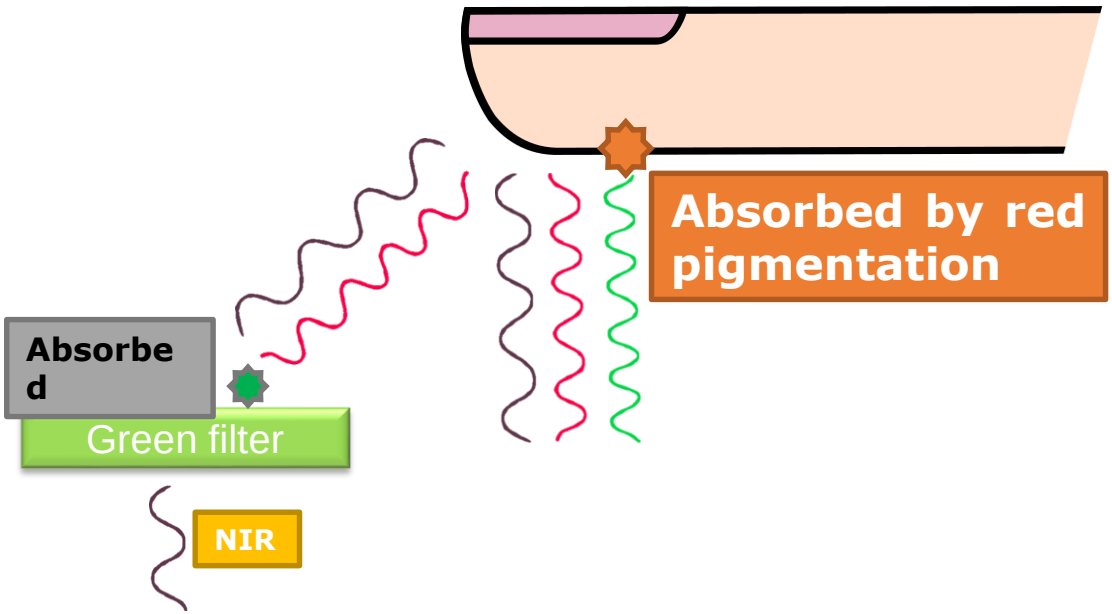
Red and NIR for Oxygen Saturation Measurement

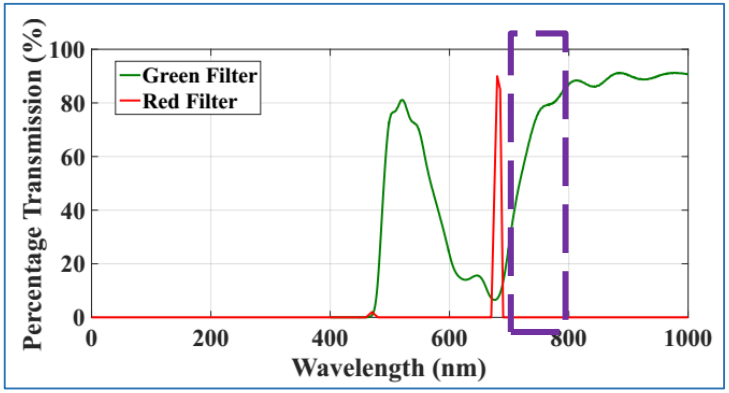




NIR **has similar characteristics of hemoglobin absorption** with the IR lights.
is **available in most of phone's flashlight** and is **not filtered by the phone's camera.**

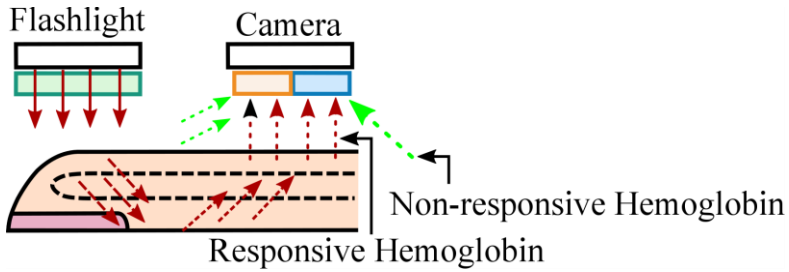
PhO_2 NIR Extraction Technique





Red and Green filter cuttoff

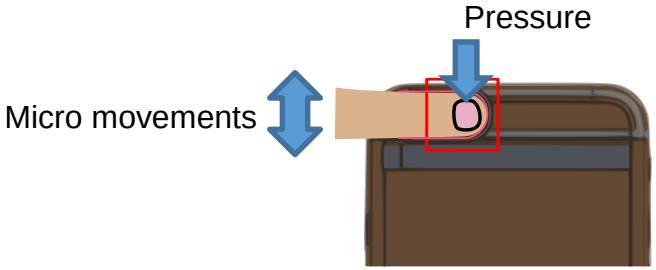
And 5 More Challenges…



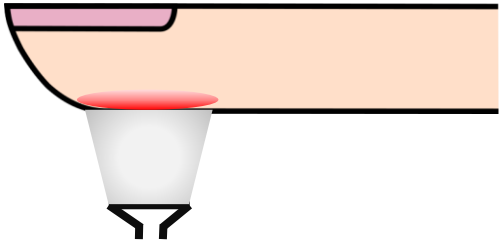
Smartphone's camera picks up most of the lights

RGB ⇔ Intensity

Conversion between RGB and light intensity

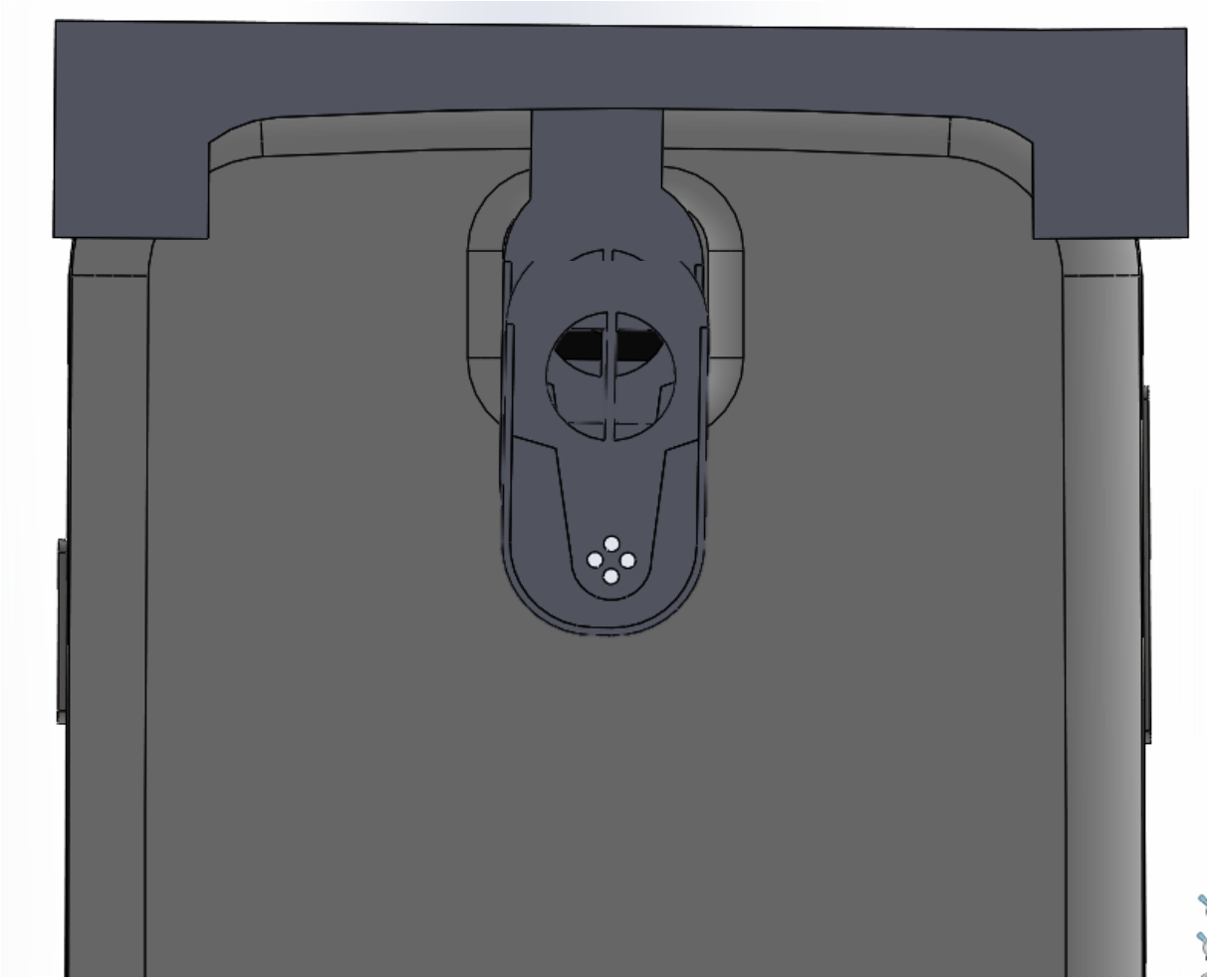


Finger movement and Contact pressure



Flashlight heat can cause skin burn

3D printed Optical Hardware Add-on



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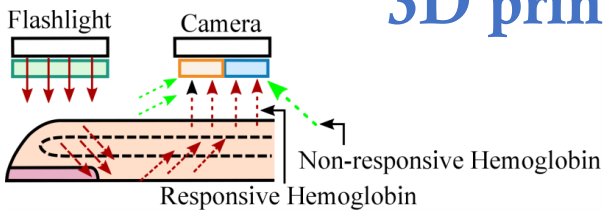

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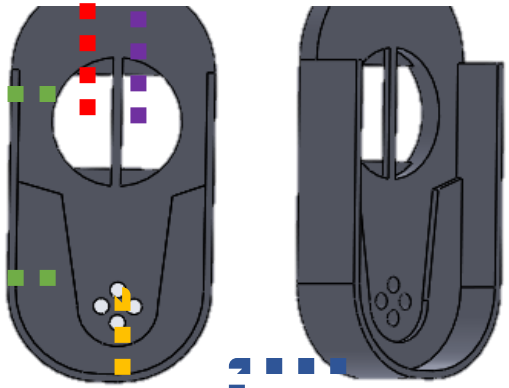
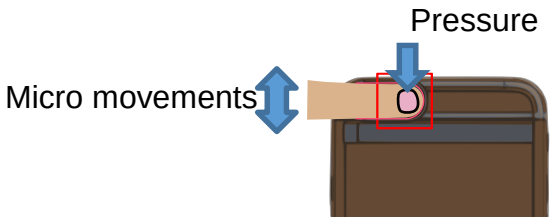
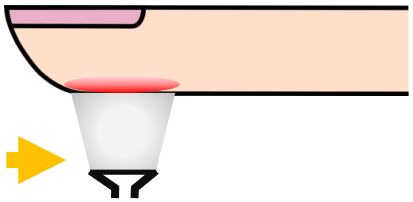






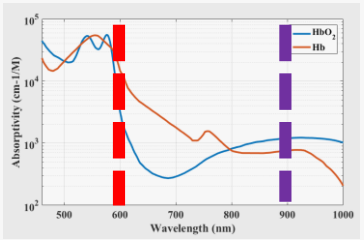
Finger movement and contact pressure

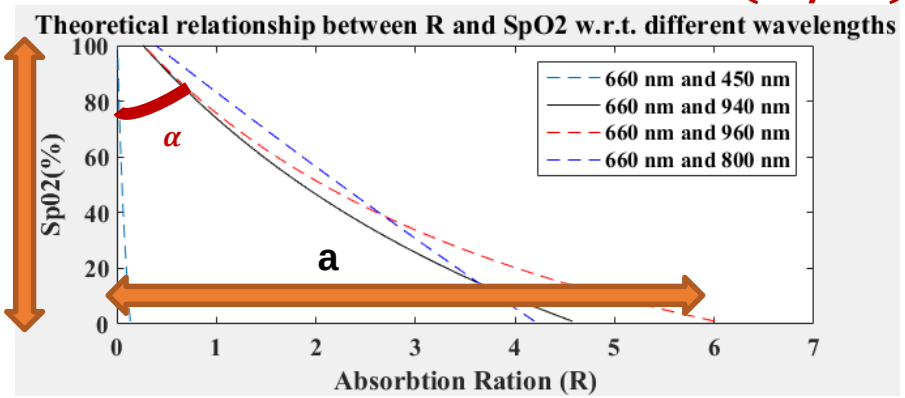
Flashlight can cause skin burn

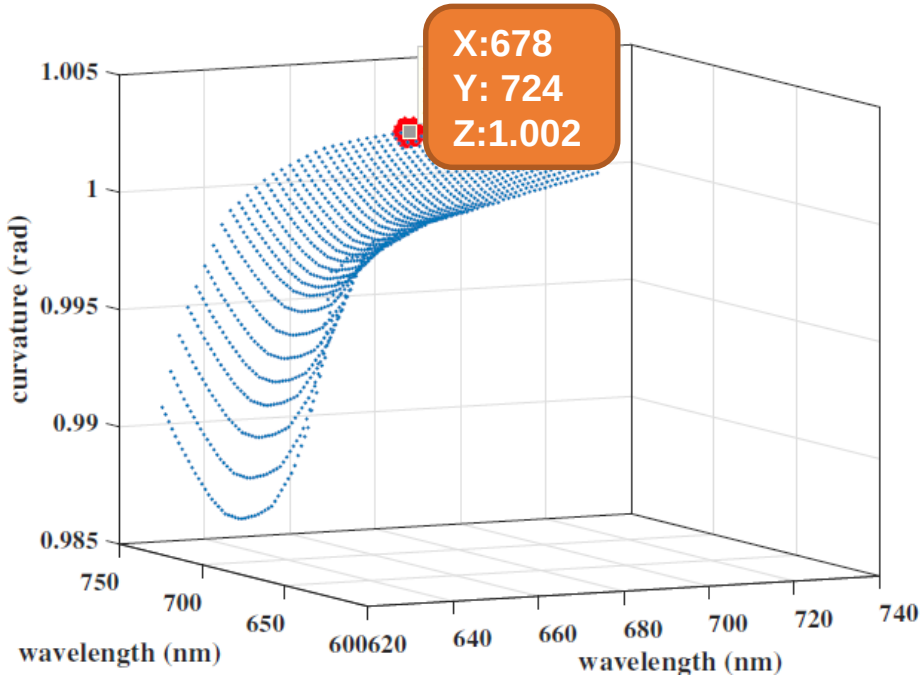
Wavelength selection

$$\alpha = arctan(a/b)$$

$$Sp02 = \frac{\varepsilon_{Hb}(r) - \varepsilon_{Hb}(r)R}{\varepsilon_{Hb}(ir) - \varepsilon_{HbO_2}(r) + [\varepsilon_{HbO_2}(ir) - \varepsilon_{Hb}(ir)]R}$$



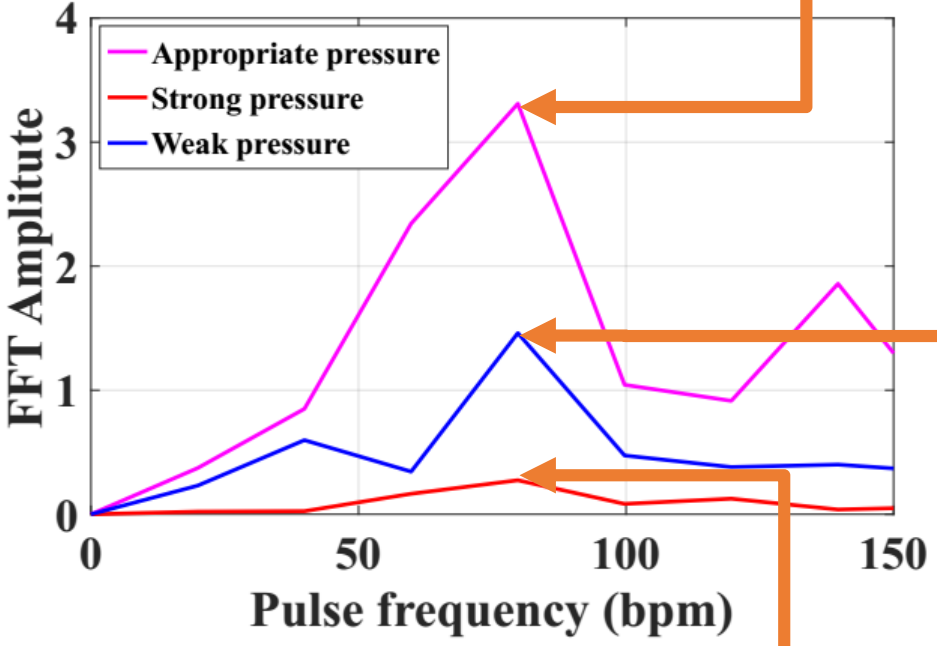


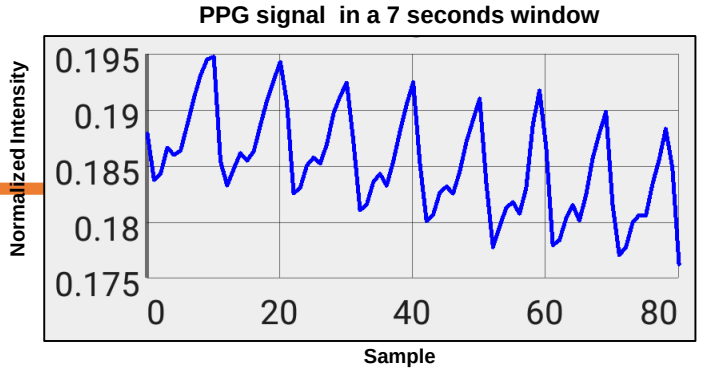


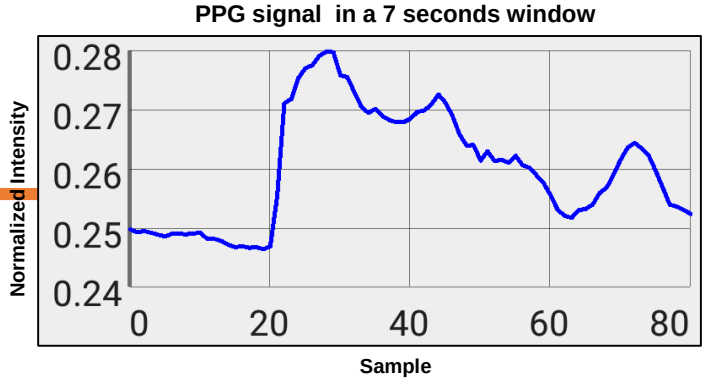
λ_R= 678 nm

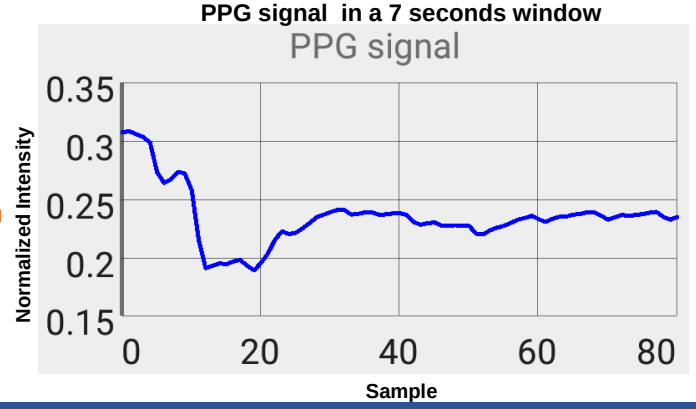
λ_{NIR}= 724 nm

Pressure Detection and Recommendation



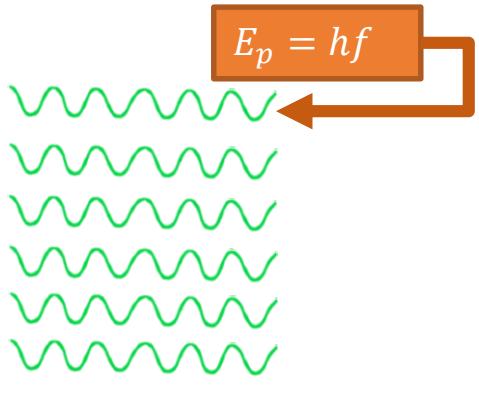


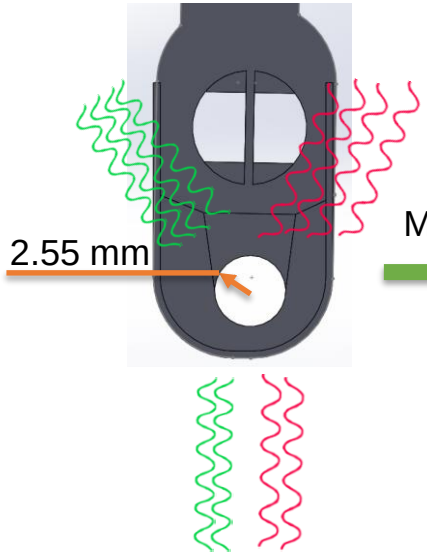




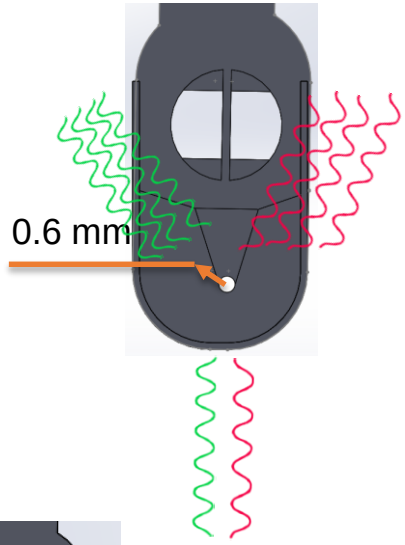
Heat Reduction with Distributed Lighting Source

$$H \propto E = \{$$



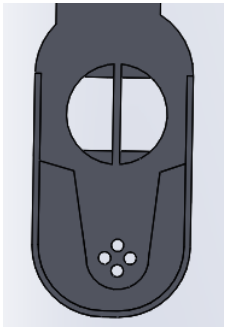


Modify

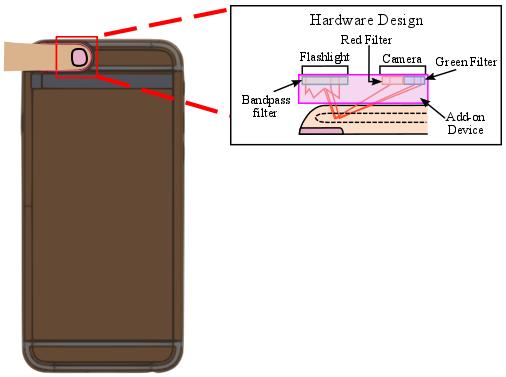


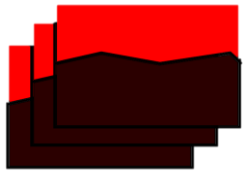
Bandpass filte

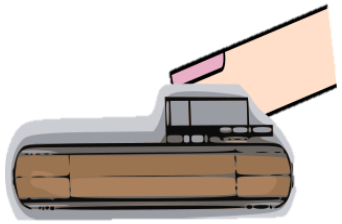
To maintain the high light intensity



PhO_2 Algorithms

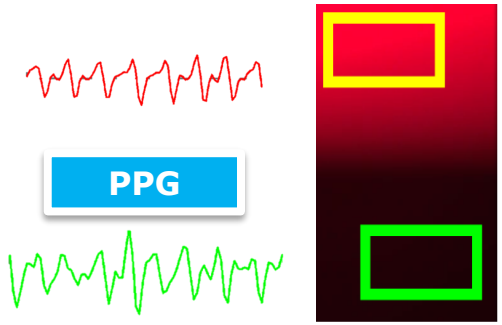




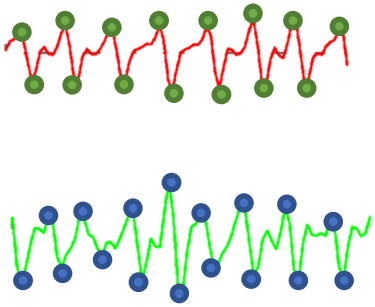


Detecting pressure

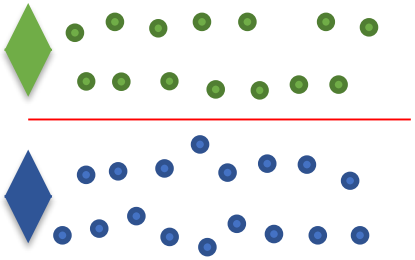
Collecting raw data



ROI detection and create the PPG signals



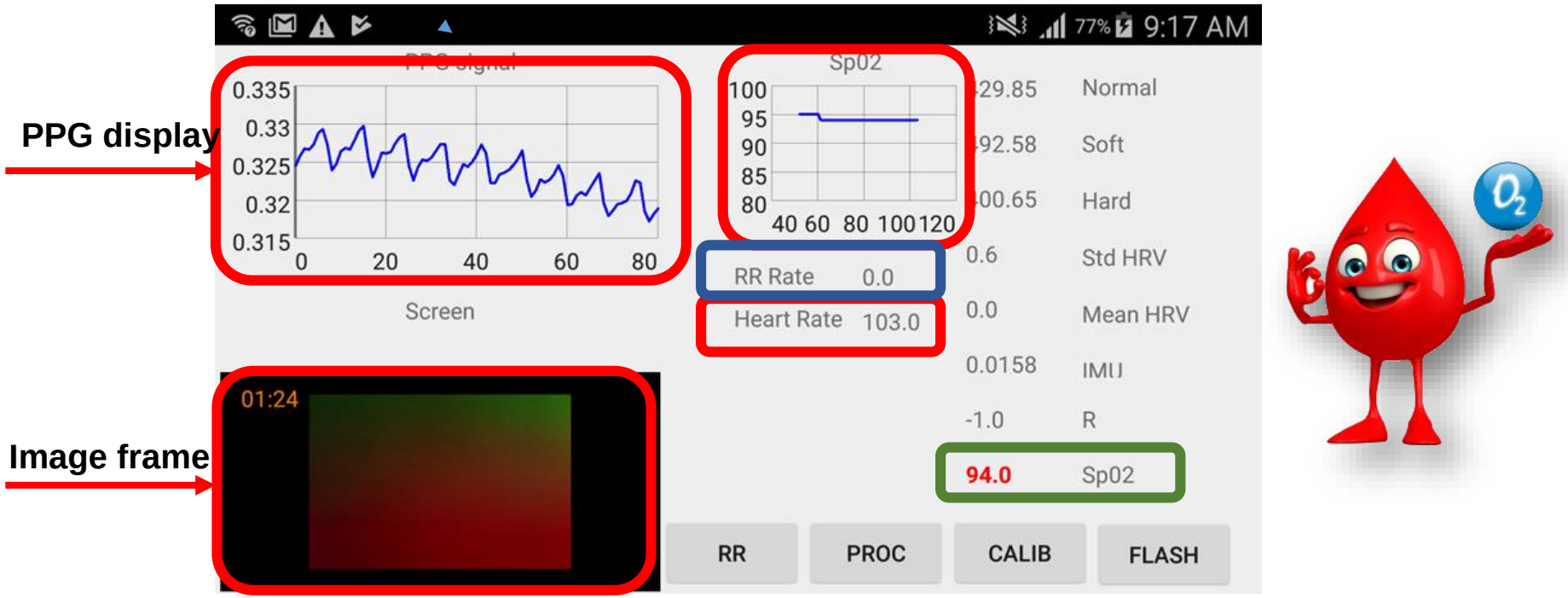
Identify the peaks and troughs

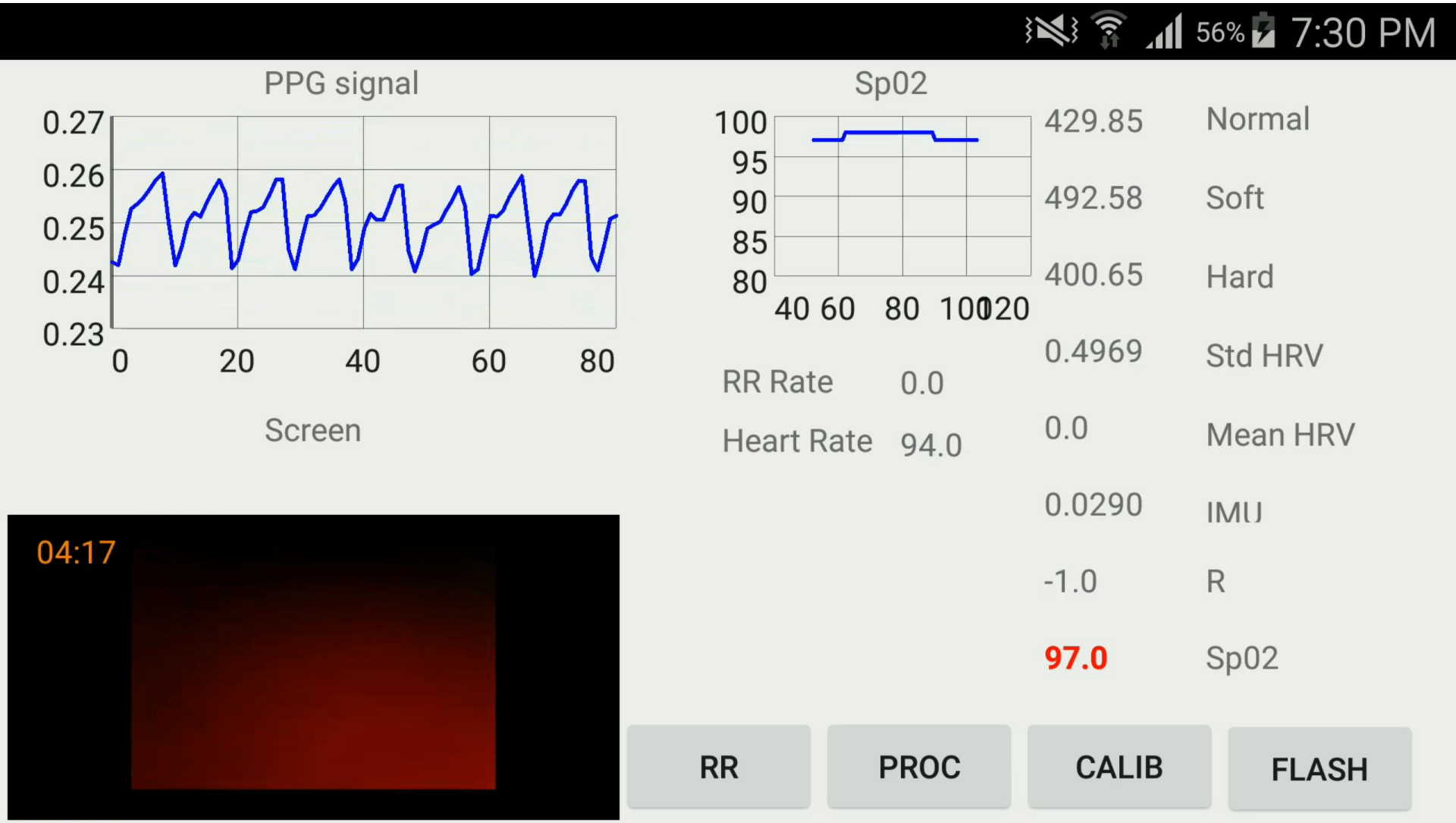


Calculate peak-to-peak ratio

95 %

App overview

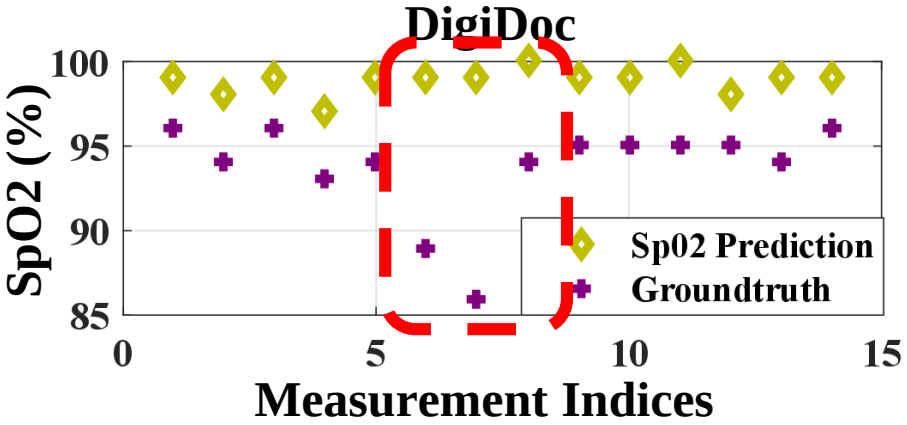


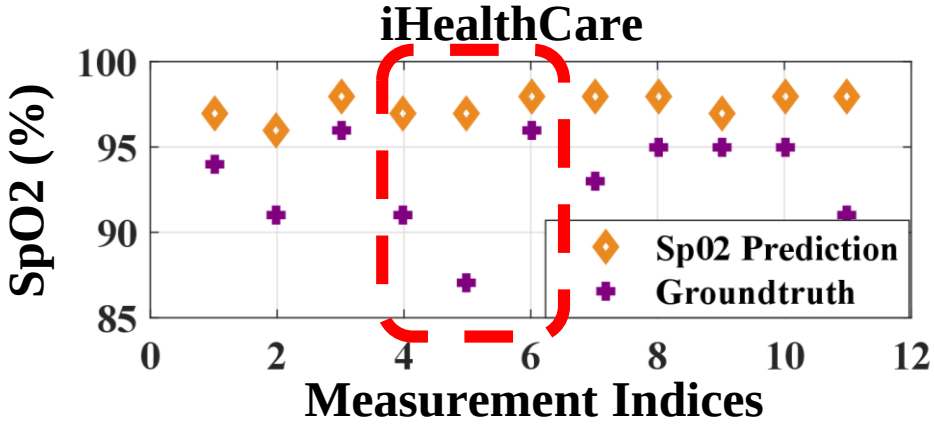

56% 7:30 PM
PPG signal
0.27
0.26
0.25
0.24
0.23
0
20
40
60
80
Screen
Sp02
100
95
90
85
80
40 60 80 100 120
RR Rate 0.0
Heart Rate 94.0
429.85 Normal
492.58 Soft
400.65 Hard
0.4969 Std HRV
0.0 Mean HRV
0.0290 IMU
-1.0 R
97.0 Sp02
04:17
RR
PROC
CALIB
FLASH

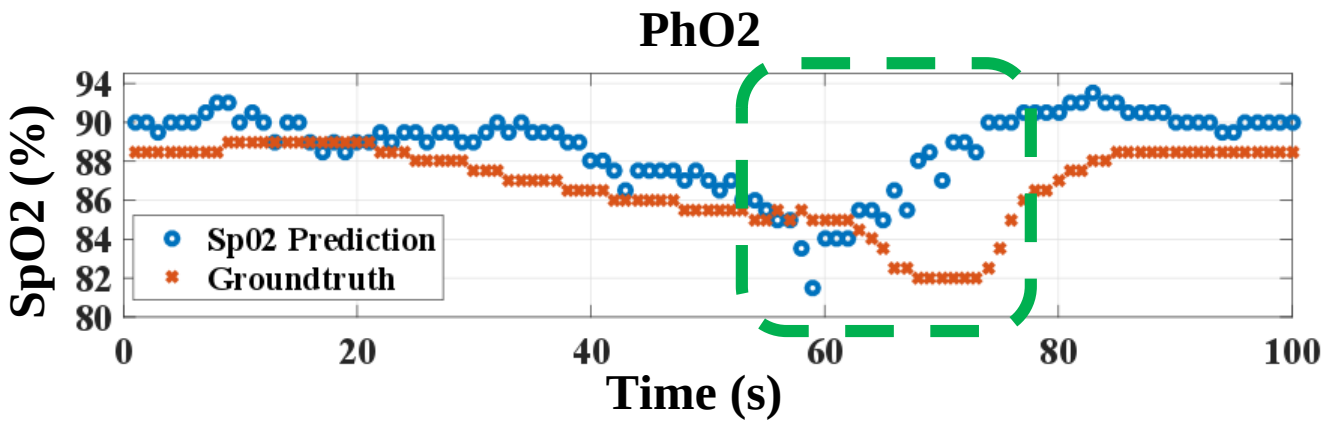
In-lab experiments

- **3 males, 3 females**
- **5 times performs the *hyperventilation* (a breath holding technique to reduce oxygen).**
- **Totally 560 samples.**

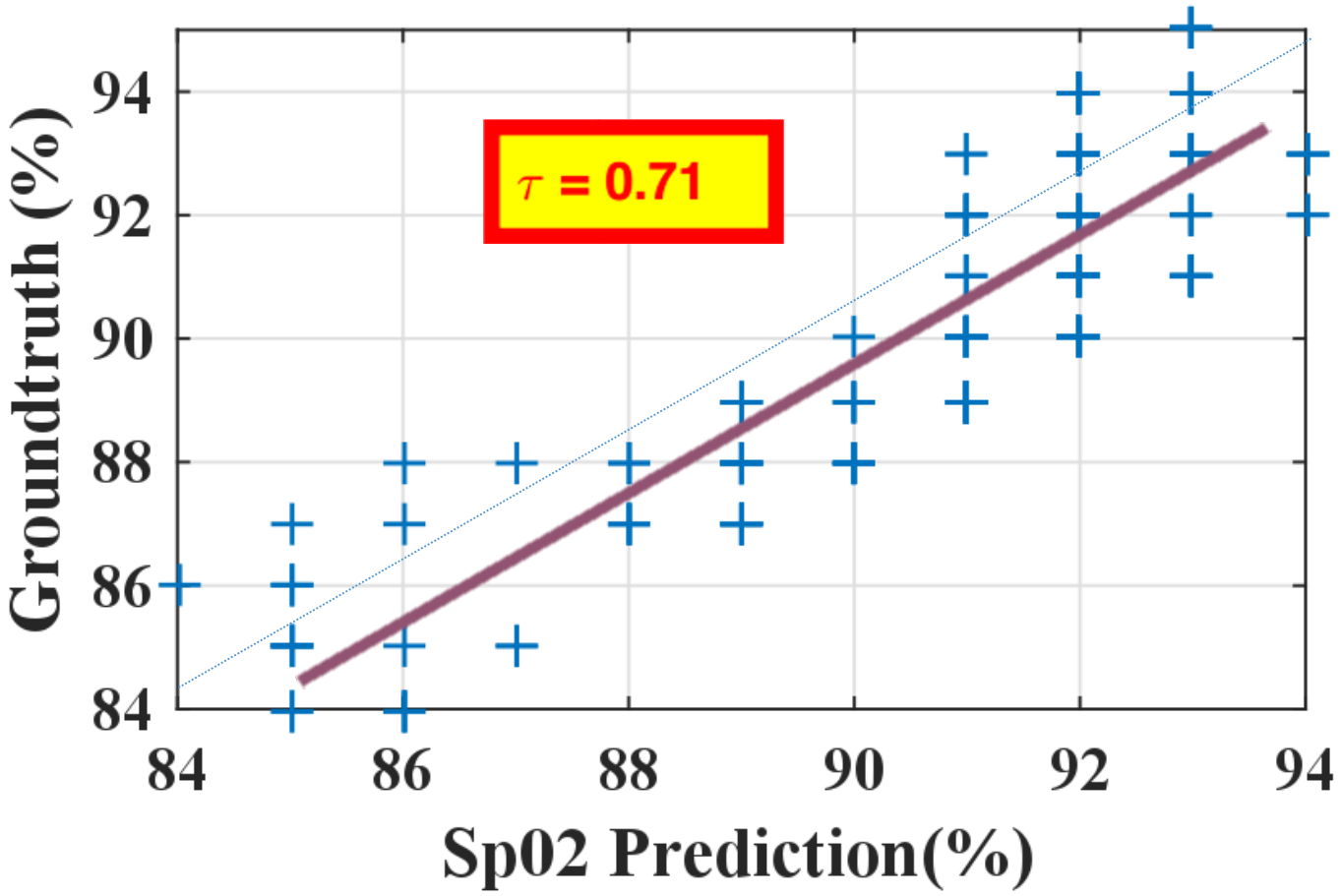
PhO2 vs. Existing apps





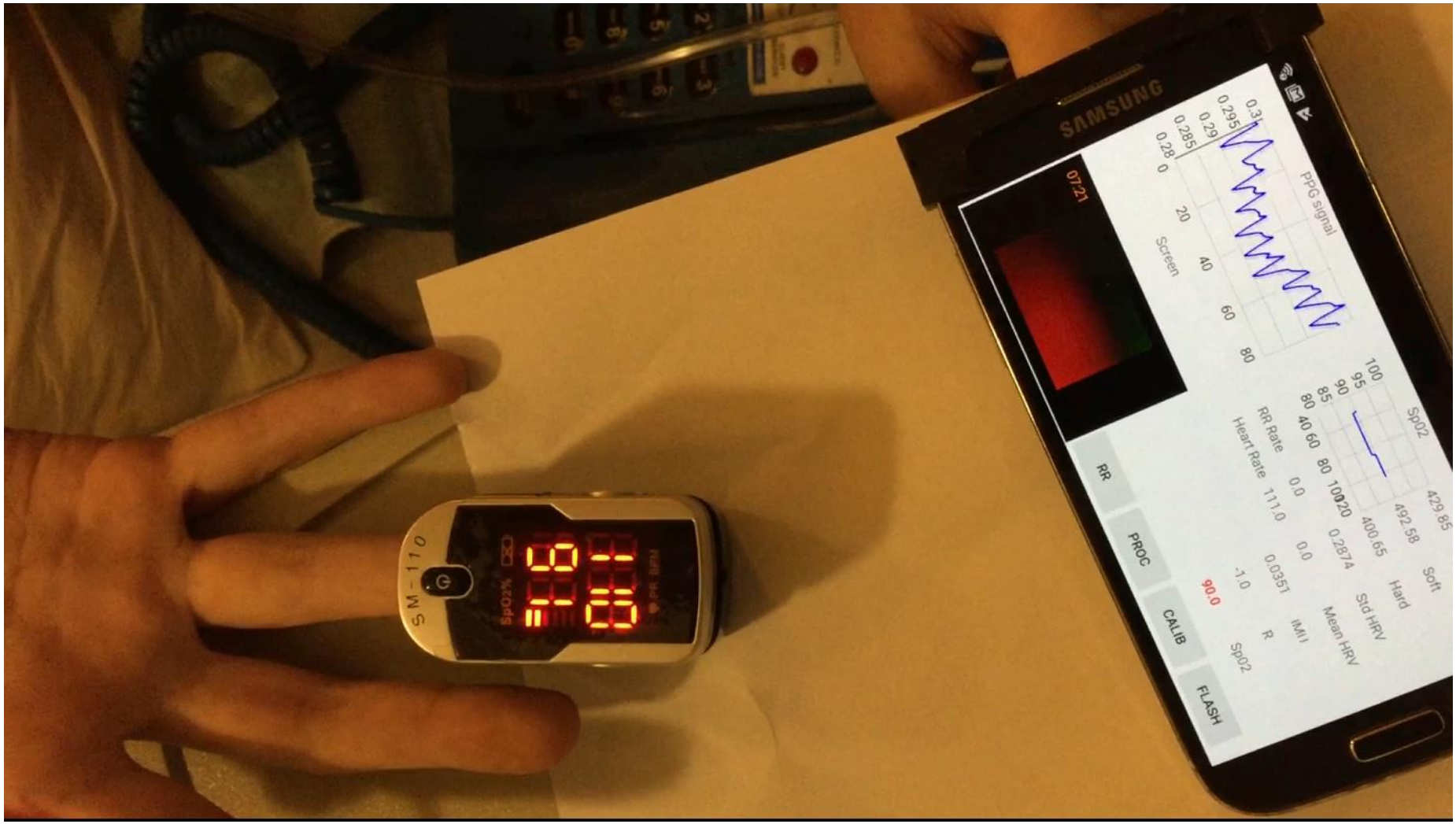


Experimental results

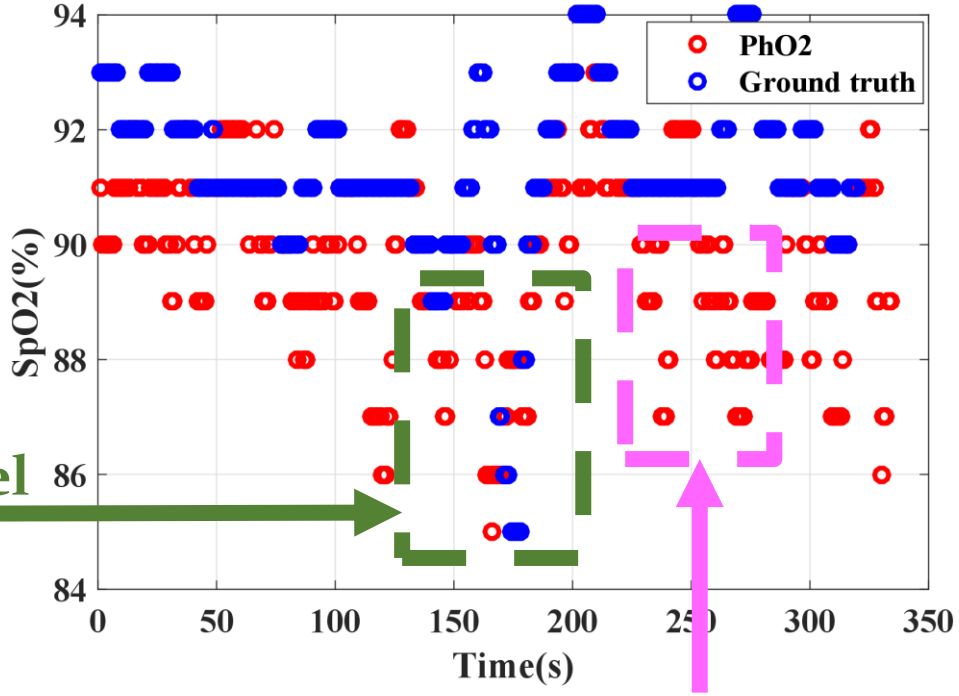


3.5%

In hospital experiment with patient.



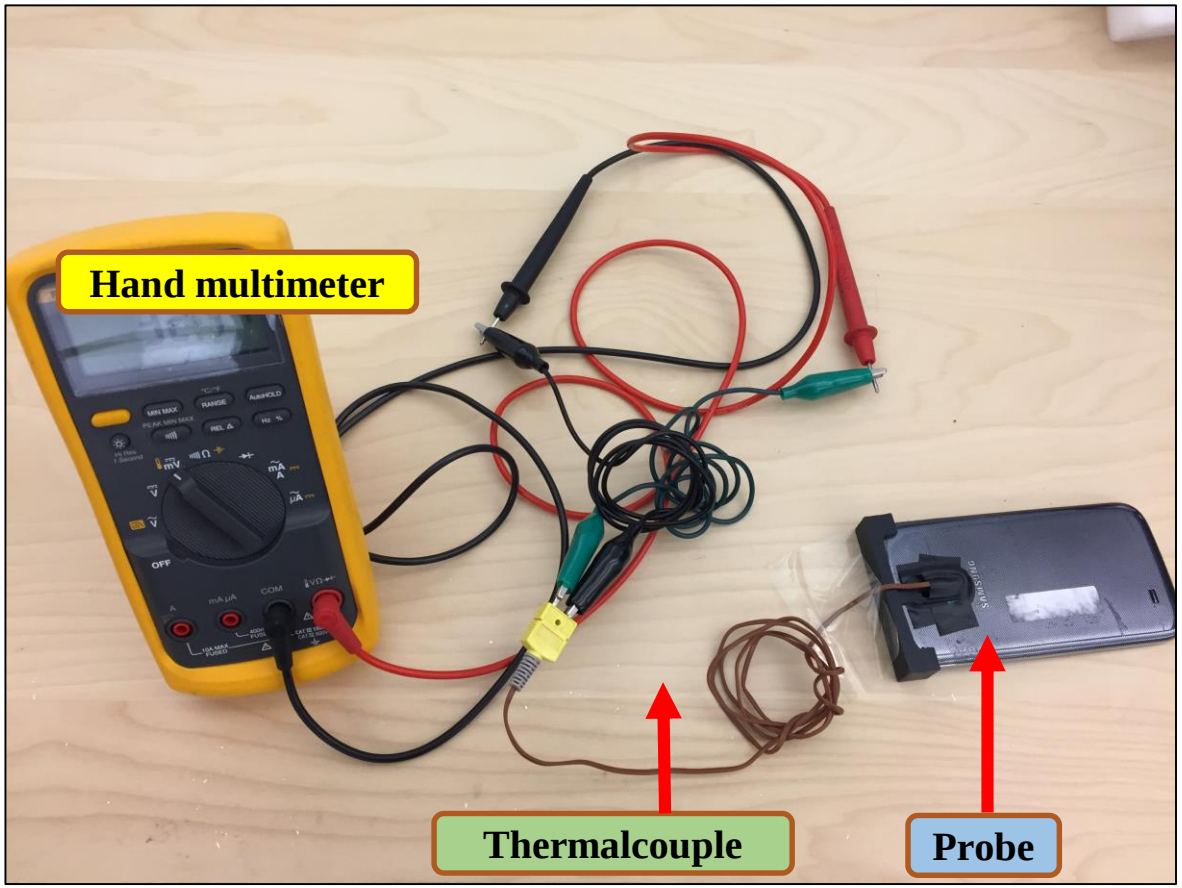
Fine-grained evaluation of the patient



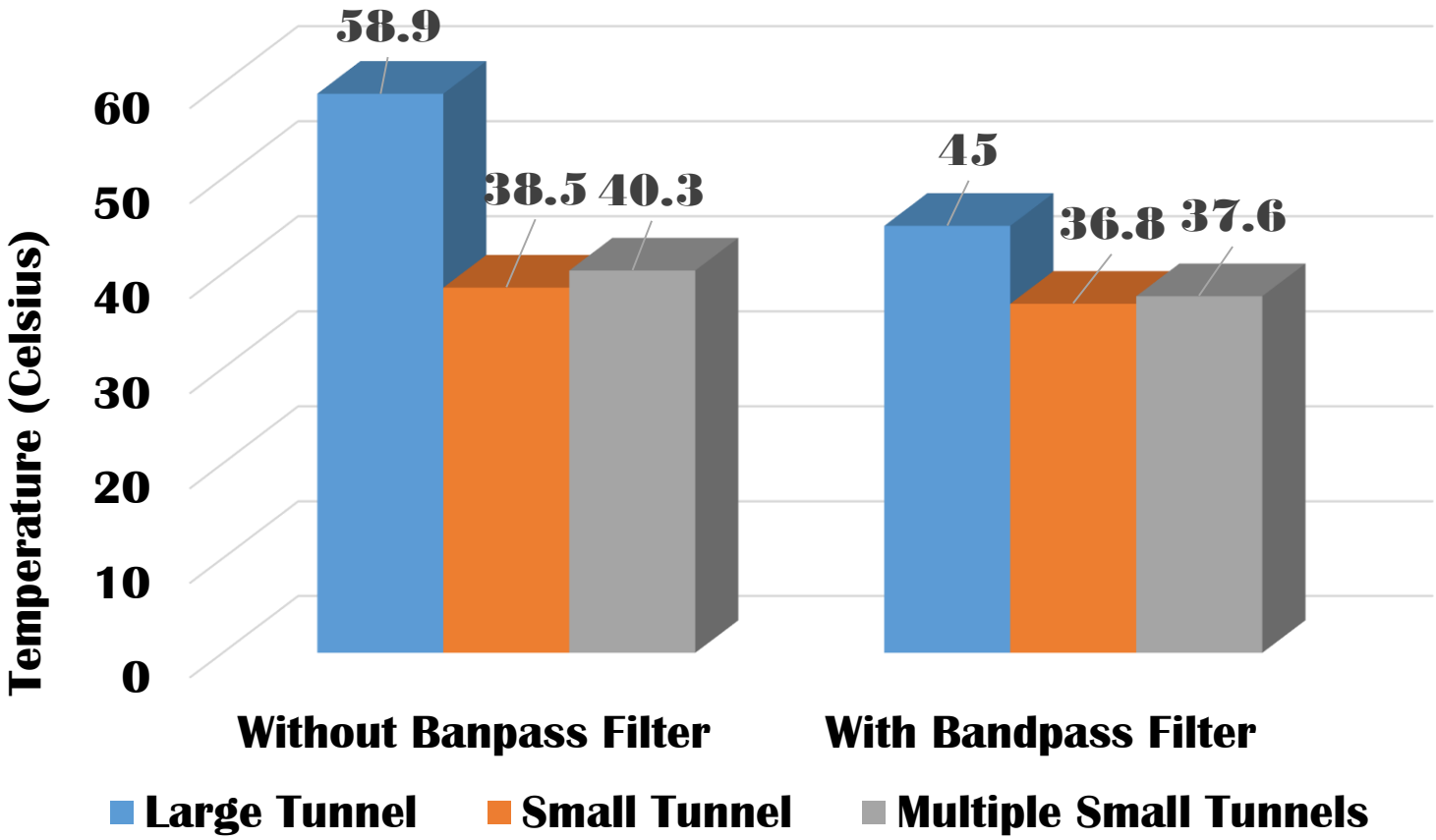
Low Oxygen Level

Coughing

Heat Reduction Evaluation



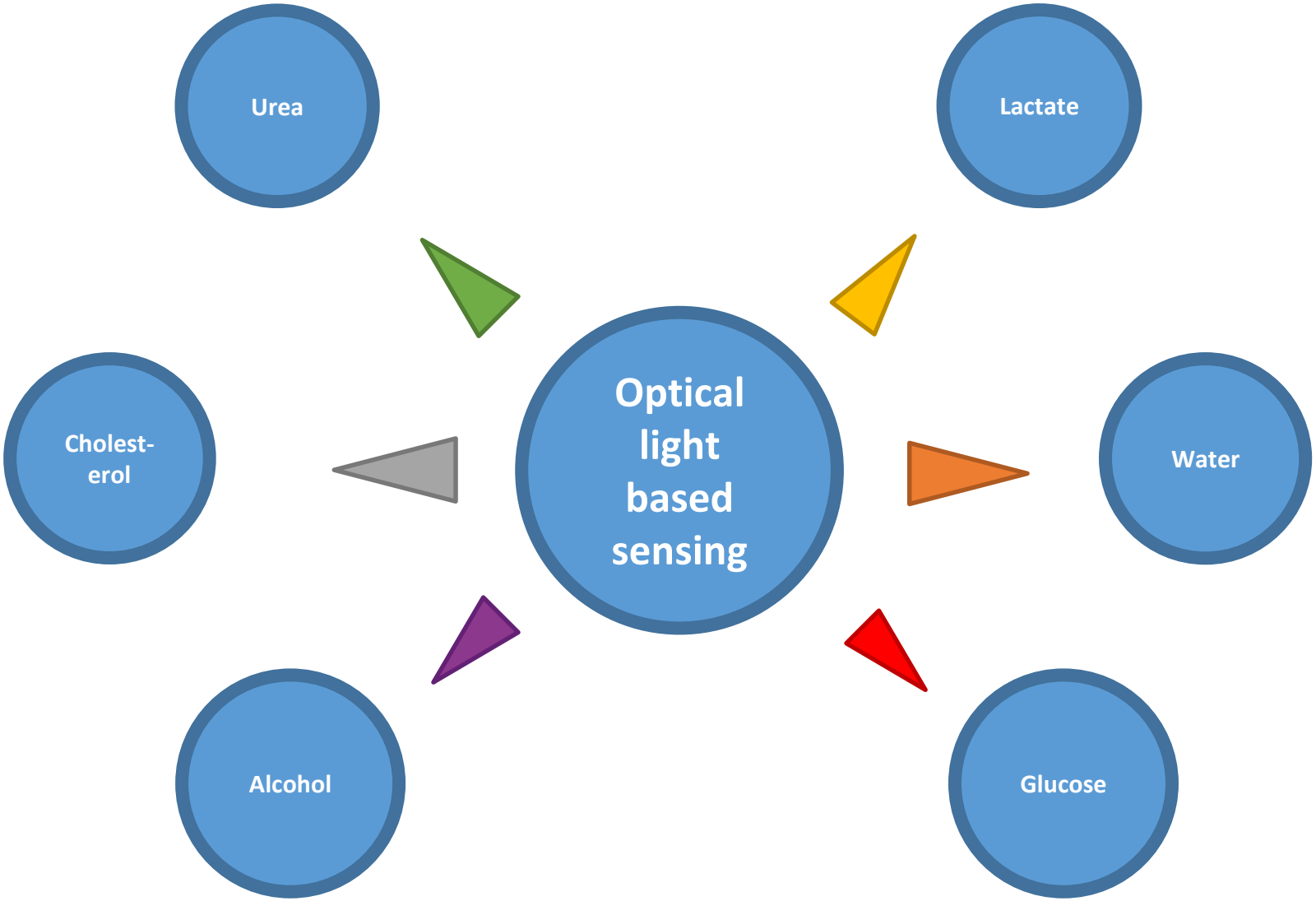
Output temperature of different add-on designs



Conclusion

- **Accurately measuring oxygen level using low-cost optical film filters.**
- **Detect the appropriate contact pressure between finger and phone' camera.**
- **3D-printed add-on to handle the problem of light scattering and finger movement.**

Application for optical light based sensing



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