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

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Chronic Obstructive Pulmonary Disease (COPD)

24 Million Americans have COPD

Leading cause of death in the US, 2016

Early detection of COPD is key to successful treatment

OFTEN FOUND IN LATE STAGE

$34,000 treatment in ICU
Vital signs screening in COPD

Heart rate

Breathing rate

Wheezing sound

Oxygen saturation needs to be measured frequently

Oxygen saturation (SpO2)
Oxygen Saturation ($\text{SpO}_2$)

$$\text{SpO}_2 = \frac{\text{No. oxygenated hemoglobin}}{\text{Total No. hemoglobin}} \times 100\%$$
Non-invasive Measurement of Oxygen Saturation

\[ SpO_2 = f \left( \frac{AC_R}{AC_{IR}} \right) \]
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

IR emitter

Red emitter

PHONE BASED PULSE OXIMETER

Light Source
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. It is available in most of phone’s flashlight and is not filtered by the phone’s camera.
PhO$_2$ NIR Extraction Technique

Absorbed by red pigmentation

Green filter

NIR

Red and Green filter cuttoff
And 5 More Challenges…

Smartphone’s camera picks up most of the lights

Conversion between RGB and light intensity

Finger movement and Contact pressure

Flashlight heat can cause skin burn
3D printed Optical Hardware Add-on
3D printed Optical Hardware Add-on

- Smartphone’s camera picks up most of the lights
- Conversion between RGB and light intensity
- Finger movement and contact pressure
- Micro movements
- Flashlight can cause skin burn
Wavelength selection

\[ \alpha = \arctan\left(\frac{a}{b}\right) \]

\[ \text{SpO2} = \frac{\varepsilon_{Hb}(r) - \varepsilon_{Hb}(r)R}{\varepsilon_{Hb}(ir) - \varepsilon_{HbO2}(ir) + \left[\varepsilon_{HbO2}(ir) - \varepsilon_{Hb}(ir)\right]R} \]

\[ \lambda_R = 678 \text{ nm} \]

\[ \lambda_{NIR} = 724 \text{ nm} \]
Pressure Detection and Recommendation

![Diagram showing FFT Amplitude and Pulse frequency (bpm)]

- **Appropriate pressure**
- **Strong pressure**
- **Weak pressure**

Normalized Intensity

PPG signal in a 7 seconds window

Sample
Heat Reduction with Distributed Lighting Source

\[ H \propto E \]

\[ E_p = hf \]

Modify Bandpass filter

2.55 mm

0.6 mm

To maintain the high light intensity
Detecting pressure and create the PPG signals

Collecting raw data

Identify the peaks and troughs

Calculate peak-to-peak ratio

ROI detection and create the PPG signals

PhO₂ Algorithms

Collecting raw data

95%
App overview

PPG display

Image frame
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

**DigiDoc**

- SpO2 (%) vs. Measurement Indices
- SpO2 Prediction
- Groundtruth

**iHealthCare**

- SpO2 (%) vs. Measurement Indices
- SpO2 Prediction
- Groundtruth

**PhO2**

- SpO2 (%) vs. Time (s)
- SpO2 Prediction
- Groundtruth
Experimental results

\[ r = 0.71 \]

3.5%
In hospital experiment with patient.
Fine-grained evaluation of the patient

Low Oxygen Level

Coughing
Heat Reduction Evaluation

Hand multimeter

Thermocouple

Probe
Output temperature of different add-on designs

Without Banpass Filter
- Large Tunnel: 58.9
- Small Tunnel: 38.5
- Multiple Small Tunnels: 40.3

With Bandpass Filter
- Large Tunnel: 45
- Small Tunnel: 36.8
- Multiple Small Tunnels: 37.6
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

- Urea
- Lactate
- Cholesterol
- Water
- Alcohol
- Glucose

Optical light based sensing
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