Redesigning the Pulse Oximeter

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Introduction

Many medical devices in the present day are shifting away from using invasive procedures to measure biomarkers such as temperature and heart rate and towards techniques that allow for faster, painless measurements. In particular, light has enabled medical technology to make this shift. Infrared light, when harnessed properly, has the ability to read temperature through infrared thermography, and assess blood oxygenation levels through pulse oximetry technology, and X rays have long been able to image parts of the body that otherwise were impenetrable. This paper focuses on how the human eye perceives visible light and the complications that can occur when light-based medical technology is applied to diverse populations. This is especially important because medical technologies discovered in the 20th century were often only calibrated on Caucasian patients, leading to a larger margin of error for patients of color.

Heading 1

Why Light?

From your high school chemistry classes you may remember that light acts as both a particle and a wave. In this article, we will focus on light's properties as a wave. As humans, everything we see is visible because of light. This holds true even "in the dark"--we are able to discern the vague outlines of objects around us because our eyes are still picking up on the ambient light in the room. The colors we associate with objects are a function of light, and without light it would be impossible for us to visually distinguish objects.

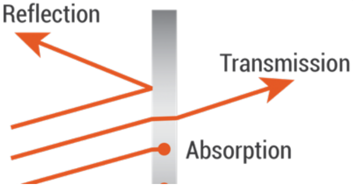
The colors we see are produced by the absorption or reflection of available light. When we see an apple that is red in color, colloquially we say that the apple *is* red. Scientifically speaking, however, the apple is actually *reflecting* the color red back to us, and absorbing every other color. Confused? Let's break this down a little more.

Absorbance and Reflection

Have you ever touched the hood of a black car on a sunny day? It's hot! Black is the absence of all of the colors in the rainbow, and sunlight contains all of the colors in the rainbow, which is a type of light we classify as "white light". Every shade of light has a different wavelength, and every wavelength corresponds to a different amount of energy that the "particles" of light, known as photons, carry. When a beam of sunlight hits a black hood of the car, the material making up the hood absorbs all of the photons in the beam.

On the other hand, white is a mixture of all of the colors in a visible spectrum, and when white light comes into contact with a white material all of the wavelengths of light are reflected, and none of the energy is absorbed into the white material. This is why in the winter we tend to wear dark colors, and in the summer we wear lighter colors.

Now that we've discussed the absorption and reflection properties of light, we may move on and discuss a third property: transmittance.



We see transmittance occur daily when light passes *through* the glass of a window or through your finger when you shine light. Transmittance differs from absorbance because the light leaves the material after entering it. Absorbed light enters the material and does not leave. However, transmittance and reflectance are closely related. and The relationship of these two properties is captured in Beer's Law.

Beer's Law

Beer's law, discovered by August Beer in 1852, allows people to calculate how much light will be absorbed by a liquid of a given concentration using the wavelength of the light, the properties of the liquid, and the length of the material the light needs to pass through:

$$A = \epsilon c l$$

Where A is absorbance, ϵ is the molar absorption coefficient, c is the molar concentration of the liquid, and l is the length of the optical path.

The absorbance of light through a liquid is a function of the concentration of the light absorbing substance within it. The higher the concentration of light absorbing particles the more light is absorbed by the liquid, and as a result the lower and the lower the transmittance of light through the liquid. This relationship draws on the fact that very material has an absorbance spectrum. An absorbance spectrum visually depicts how well a material absorbs different wavelengths of light. Going back to example of the red apple, when we look at the apple all we know is that the object reflects red light, but we don't know anything about what light it will absorb. If we looked at the absorbance spectrum of the skin of the apple, then we could see which wavelengths of light it will absorb, and how much it will absorb.

Optical Properties in Pulse Oximetry

Absorbance, reflectance, and transmittance all come into play when we examine medical devices. In the pulse oximeter, oxygen saturation in blood is measured noninvasively by shining two wavelengths of light at 660 nm and 940 nm onto a patient's finger. Deoxygenated hemoglobin has a higher absorption at 660 nm, which represents a dark maroon color, and oxygenated hemoglobin has a higher absorption at 940 nm, which represents a brighter red color that is traditionally associated with blood. On the opposite side of the finger from the LEDs a photodetector receives the light that is transmitted through the finger. The light being transmitted changes as blood pumps through the finger, and so this is an alternating signal. This received signal is then divided by a DC signal generated at the same wavelength of light, which hypothetically should divide out the common effects of the tissue, skin, and venous blood that exist in both the AC and DC signal. In reality, dividing by the DC signal does not always successfully eliminate the effects of the finger. This has been seen in multiple research studies where patients with dark skin tones receive larger errors in their pulse oximetry readings than Caucasian patients. Dark skin would affect the oximetry readings because melanin, the molecule that gives pigment to skin, has a similar absorbance spectrum to oxygenated hemoglobin. If the effect of skin is not properly divided out the melanin would cause less light to be transmitted to the photodetector, which would result in a mistaken recorded reading of higher oxygenated hemoglobin.

Conclusion

Traditionally we think that engineers need specific knowledge on a topic to create a product, and consumers use the product and have no need for the background knowledge that went in to making it. Doctors and paramedics may have a strong understanding of the human body, but if they don't understand the underlying concepts of the technology assisting their diagnoses, they are bound to miss important nuances. This can have dire consequences when the errors in prognosis are not random but in fact systemic and a function of the technology's design. The significant variation in the pulse oximeter's performance on skin of to color, and its contribution to vast inequities in healthcare in the U.S., is a key example of why everyone should stay curious about how the technology they are using works.

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