# Supplementary Information

## ***Drawbacks of external lighting***

One key motivation for the hardware accessory presented in this paper is the ability to isolate the test strip from ambient lighting conditions. This is especially important for the application of sweat monitoring for athletes, as solar light intensity will change markedly over the course of a several hour run, and naturally cannot be used at all after dusk. To demonstrate the effect of lighting variations, we first measured the RGB intensity of pH test strips from known buffer solutions in ambient incandescent light, and in semi-transparent 3D printed plastic holder (Fig. S1).

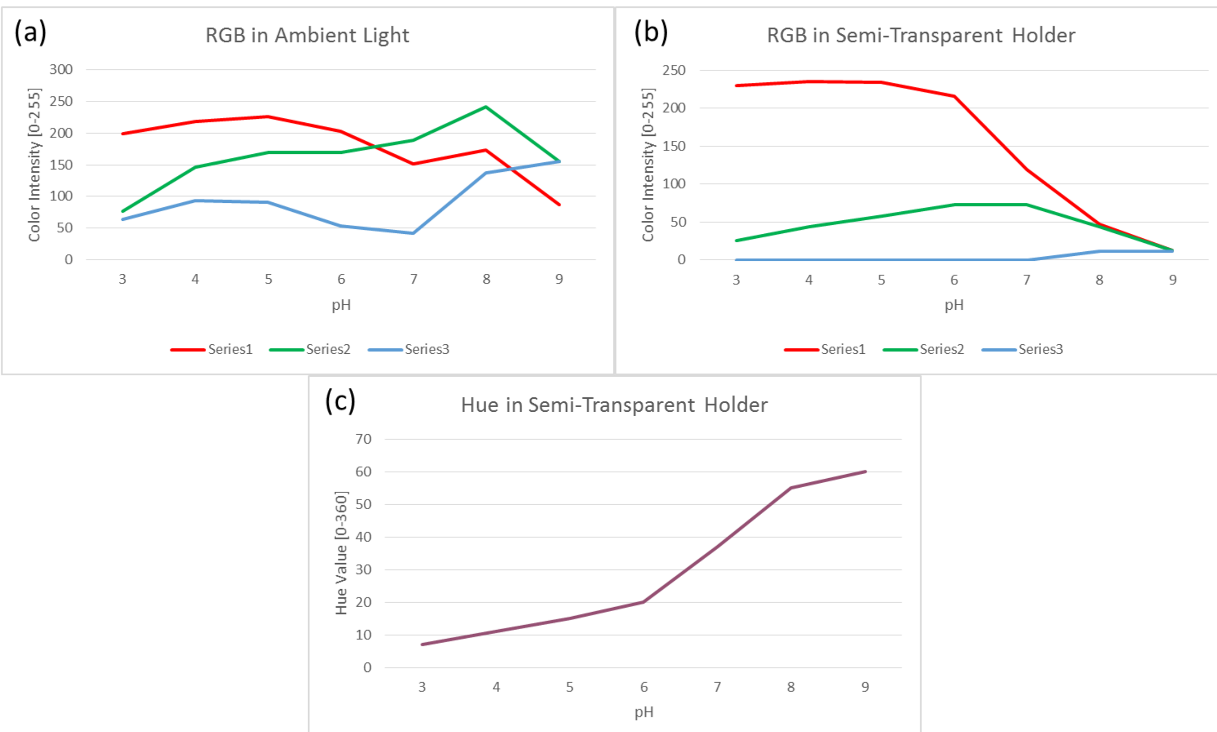


Figure S1: A comparison of RGB and hue values for buffer solutions in different lighting conditions. (a) RGB channels in ambient incandescent light. (b) RGB channels in a semi-transparent plastic holder. (c) The hue to pH curve after transforming the results in (b) to the alternate color space.

Outside of the holder, the measured RGB values can fluctuate greatly over a very small pH range because of changes in the intensity of the light source and the exact positioning of the test strip relative to the smartphone camera and the light source. While it is possible to diminish these deviations with a reference color chart, errors in positioning can still lead to systematic errors in the measured pH values. The semi-transparent 3D printed holder produces a smoother curve with less random variations, but crucially blocks out most of the blue channel, which is a crucial measure to distinguish high pH values on most universal indicator strips. This also does not address the inability to use external lighting reliably in dark conditions, which would be desirable for many potential applications. To address these remaining issues, we chose to instead use an opaque plastic holder which is optically isolated, and to light the strip reproducibly with the smartphone camera flash.

***Hue value***

The HSL color space is a cylindrical color space, where the hue value can be thought of as angular measure of the perceived color, starting at red at 0°, and passing through green at 120° and blue at 240°.[1]

To find the hue as a value between 0 and 1, a simple piece-wise equation can be used which varies depending on the relative intensity of each of the RGB channels:[1]

$$\text{if max} = R: \quad H = \frac{\left(\frac{G - B}{R - min} + 0\right)}{6}$$

$$\text{if max} = G: \quad H = \frac{\left(\frac{B - R}{G - min} + 2\right)}{6}$$

$$\text{if max} = B: \quad H = \frac{\left(\frac{R - G}{B - min} + 4\right)}{6}$$

(where H := H + 1 if H < 0)

There are numerous advantages to using such a metric for smartphone colorimetric analysis. One key aspect is that, because of its close correspondence to the human perception of a color wheel, it is found to monotonically increase with high sensitivity over the range of most colorimetric indicator strips (which are designed for visual inspection). This does not apply for individual RGB channels, as is demonstrated in Fig. S1 (b) and (c). In the semi-transparent holder setup outlined in the previous section, the red and blue channels are insensitive over a large pH range, while the green channel is not monotonic. Even before resolving the light intensity problems, the hue value curve for the same data, by comparison, reproduces a more desirable S-curve calibration to pH, leading to a greater accuracy in the final pH measurement.

Another, perhaps less obvious, advantage of the hue value for specifically smartphone-based imaging is a low degree of computational complexity. While more sophisticated color spaces, such as the CIELAB standard, have been shown to be highly accurate and sensitive for colorimetric analysis[2], the nonlinear transformations to these color spaces require significantly more computational power, which can be a serious drawback for processing on a limited-resource mobile platform.

***Flash diffuser***

One problem which must be addressed to use the flash for lighting is the short distance between the camera and the test strip. A single point light source at this distance will generate harsh gradients in light intensity across the test strip, making it impossible to obtain a single hue value that accurately reflects the color of the strip for image processing. A captured image from our device without light diffusion is shown in Fig. S2 (a). In professional photography, undesirable harsh gradients and shadows due to the camera flash are often compensated by the use of a silicone flash diffuser which spatially distributes the light source. For our device, we have constructed a similar flash diffuser from PDMS which sits in between the camera flash and the test strip. As is shown in Fig. S2 (b), the result is an elimination of reflections and lighting gradients, which yields uniform, quantifiable color intensity across the length of test strip.

(a) (b)

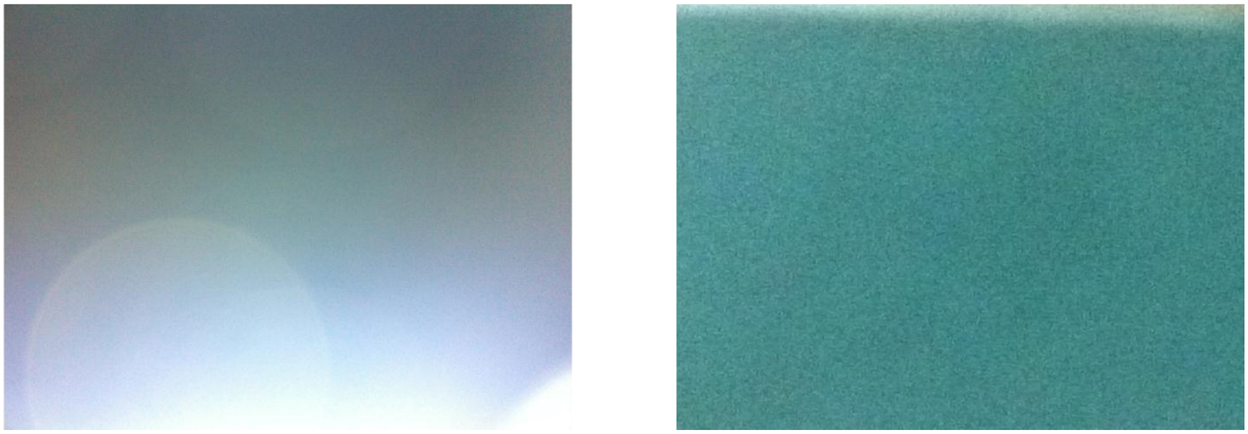

Figure S2: A comparison of a test strip in an optically isolated holder using the flash for illumination (a) without the PDMS diffuser and (b) with the PDMS diffuser.

# References

1. K. Cantrell, M. M. Erenas, I. de Orbe-Payá and L. F. Capitán-Vallvey, *Analytical Chemistry*, 2009, **82**, 531-542.
2. L. Shen, J. A. Hagen and I. Papautsky, *Lab on a Chip*, 2012, **12**, 4240-4243.