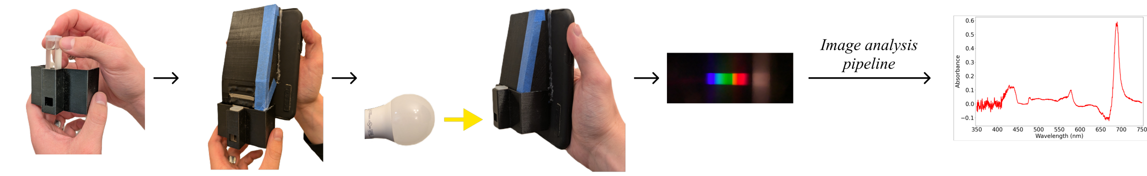
Feasibility of Smartphones for Accessible, Noninvasive Micronutrient Assessment

Andrew Balch
xxv2zh@virginia.edu
University of Virginia, USA

Afsaneh Doryab
ad4ks@virginia.edu
University of Virginia, USA



a) Vitamin B12 sample placed into cuvette
b) Cuvette holder slotted onto spectrophotometer
c) Light passes through the sample and into the device
d) Light transmitted by the sample is imaged
e) Absorbance spectra is calculated

Figure 1: Process overview of how the smartphone-based spectrophotometer is used in practice for micronutrient analysis.

Abstract

Micronutrient imbalance is a global issue, and its detection is invasive and expensive. Despite being largely preventable, imbalances of one or more micronutrients is pervasive and has major downstream health effects [1]. Women, children, and underserved populations in particular bear the greatest burden of micronutrient imbalance [4–6]. However, the true scope of this issue is often unseen and unaddressed because of the barriers to accessible micronutrient status assessment [2]. Status assessment of micronutrients is often done via indirect, subjective dietary logs, in-person clinical examinations, or complex analyses on blood (e.g. liquid chromatography-coupled mass spectrometry). While valuable, these assessments are expensive, flawed, and burdensome on the patient and the clinician.

As a step towards mitigating this barrier, we explore the application of mobile spectrophotometry to determine concentrations of B vitamins in a solution. Spectrophotometry is the analysis of light (primarily visible light) as it is absorbed and transmitted by a constituent in a solution [10]. By analyzing how much light at a particular wavelength is absorbed by the sample, we can determine the relative concentration of a constituent or even its identity.

A smartphone's camera can be a valuable tool for accessible spectrophotometric analysis [3, 7, 9, 11], but smartphone-based spectrophotometry has yet to be explored for the high-impact problem area of micronutrient assessment. After experimenting with multiple prototypes, we found that a design based on Bruininks and Juurlink [3], modified with a custom cuvette holder attachment, was the best-performing for spectral imaging (Fig. 1b). To extract absorbance spectra over the visible range (400 to 700 nm) from the smartphone camera (iPhone XR), we formalized an image analysis pipeline using ImageJ [8] and Python (Fig. 2).

Preliminary studies revealed that of three different micronutrients (vitamins B2, B7, and B12), vitamin B12 would be the best candidate for further experimentation because of its distinct, pink-red color when dissolved into distilled water. Next, we experimented with different light sources (compact fluorescent light (CFL) bulb, light-emitting diode (LED) bulb, a single two-lead LED, and a matrix of three two-lead LEDs), image processing parameters (reference calculation and averaging methods), and sample concentrations (1 to 20 mcg/mL) to optimize the quality of the derived spectra. Finally, we compared our results from the smartphone-based spectrophotometer to a laboratory device (Hach DR6000).

We found that the two most common forms of B12 (the synthetic cyanocobalamin and the biologically-active methylcobalamin) follow Lambert-Beer's law at distinct absorbance peaks (Fig. 3). Although results from the smartphone device exhibited high inter-trial variance, Lambert-Beer analysis demonstrated promising performance for determining unknown concentrations of vitamin B12 (R^2 of 0.913 vs 1.0 for the laboratory device).

ACM MobiCom '24, November 18–22, 2024, Washington D.C., DC, USA

ACM ISBN 979-8-4007-0489-5/24/11
https://doi.org/10.1145/3636534.3698861

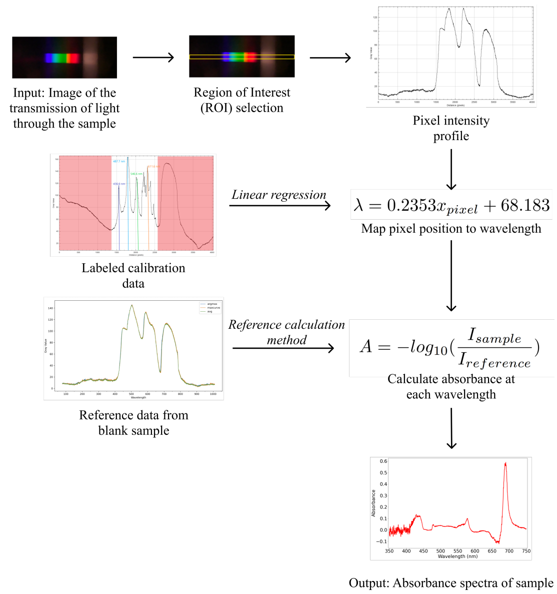


Figure 2: Flowchart of the image analysis pipeline developed extract the absorbance spectra of a sample from a smartphone image.

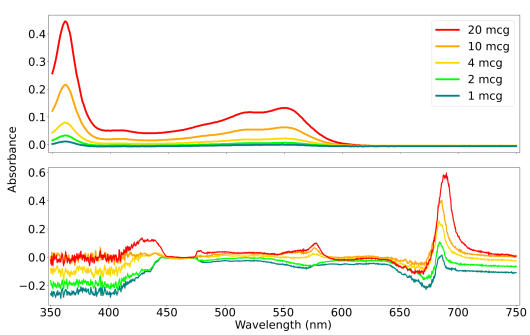


Figure 3: Absorbance peaks for different concentrations of Vitamin B12 at 361 & 551 nm for lab device (top) and 577 & 690 nm for smartphone device (bottom).

CCS Concepts

• **Applied computing** → **Health informatics**; **Health care information systems**; **Consumer health**; • **Human-centered computing** → *Ubiquitous and mobile devices*.

Keywords

health sensing, mobile health, precision nutrition, nutrition assessment, point-of-care, spectrophotometry

ACM Reference Format:
Andrew Balch and Afsaneh Doryab. 2024. Feasibility of Smartphones for Accessible, Noninvasive Micronutrient Assessment. In *The 30th Annual International Conference on Mobile Computing and Networking (ACM MobiCom '24), November 18–22, 2024, Washington D.C., DC, USA.* ACM, New York, NY, USA, 3 pages. https://doi.org/10.1145/3636534.3698861

Demo

Our demonstration will involve educating attendees on the working principles of the smartphone-based spectrophotometer, demonstrating its application for micronutrient assessment, and letting attendees get hands-on to experience the general ease of use of the system.

First, conference attendees will be shown the 3D-printed prototype device and the specifics of its design, as well as the principles of spectrophotometry, will be explained. In summation, light from a controlled source enters the smartphone attachment by passing through a very small slit. This slit is formed by two razor blades which serve to limit and direct the light transmitted through the sample. Once inside, the light bounces off a mirror and into the polycarbonate substrate of a DVD, where it is refracted (akin to prism). This refracted light is ultimately imaged by the smartphone camera sensor, where it appears as a "rainbow" of all the wavelengths of light that make up the source radiation. By attaching our cuvette holder and inserting a sample of vitamin B12, we can demonstrate in real-time how the intensity of the wavelengths as imaged by the smartphone changes.

We will then transition to a demonstration of our image analysis pipeline (Fig. 2). The smartphone image will be imported into ImageJ, where an intensity profile will be extracted and ran through our automated spectral processing program. We will demo the interactive graph of the absorbance spectra side-by-side with the original image, exploring how the rainbow-like bands translate into relative intensities for each wavelength of visible light. Finally, we will apply our calibration equation obtained by prior experimentation to determine the amount of vitamin B12 in the sample.

Last, we will offer a hands-on experience to the conference attendees, allowing them to step through a mock sample analysis with the handheld device. Two pre-made solutions of vitamin B12 (a 1 mcg/mL 'low' concentration and a 20 mcg/mL 'high' concentration) will be pipetted into a cuvette, placed in the sample holder, and imaged by attendees (see the process described in Fig. 1). This way, the change in absorbance due to different concentrations of vitamin B12 can be observed directly by attendees via comparing and contrasting between their own spectral images. We will also have three different light sources set up (CFL bulb, LED bulb, and a single two-lead LED) to demonstrate the impact of a well-selected light source on spectrophotometric results.

Acknowledgments

Special thanks to Kyan Yang for his help programming the image analysis pipeline, and to the anonymous reviewers for their constructive feedback.

References

[1] Regan L. Bailey, Keith P. West Jr., and Robert E. Black. 2015. The Epidemiology of Global Micronutrient Deficiencies. *Annals of Nutrition and Metabolism* 66, Suppl. 2 (2015), 22–33. https://doi.org/10.1159/000371618

[2] Andrew Balch, Maria A. Cardei, Sibylle Kranz, and Afsaneh Doryab. 2024. Towards an Accessible, Noninvasive Micronutrient Status Assessment Method: A Comprehensive Review of Existing Techniques. https://doi.org/10.48550/arXiv.2408.11877 arXiv:2408.11877 [cs, q-bio].

[3] Bram Bruininks and Ludo B. F. Juurlink. 2022. An Inexpensive 3D Printed Periscope-Type Smartphone-Based Spectrophotometer for Emission, Absorption, and Fluorescence Spectrometry. *Journal of Chemical Education* 99, 5 (May 2022), 2168–2174. https://doi.org/10.1021/acs.jchemed.2c00060 Publisher: American Chemical Society.

[4] Maaike J Bruins, Roland Kupka, Michael B Zimmermann, Georg Lietz, Reina Engle-Stone, and Klaus Kraemer. 2016. Maximizing the benefits and minimizing the risks of intervention programs to address micronutrient malnutrition: symposium report. *Maternal & Child Nutrition* 12, 4 (Oct. 2016), 940–948. https://doi.org/10.1111/mcn.12334

[5] Victoria Drake. 2018. Micronutrient Inadequacies in the US Population: an Overview. https://lpi.oregonstate.edu/mic/micronutrient-inadequacies/overview

[6] A. Christine Hummell and Michael Cummings. 2022. Role of the nutrition-focused physical examination in identifying malnutrition and its effectiveness. *Nutrition in Clinical Practice* 37, 1 (Feb. 2022), 41–49. https://doi.org/10.1002/ncp.10797

[7] William J. Peveler and W. Russ Algar. 2021. Toward Clinical Applications of Smartphone Spectroscopy and Imaging. In *Portable Spectroscopy and Spectrometry*. John Wiley & Sons, Ltd, 199–226. https://doi.org/10.1002/9781119636489.ch32 Section: 10 _eprint: https://onlinelibrary.wiley.com/doi/pdf/10.1002/9781119636489.ch32.

[8] Caroline A. Schneider, Wayne S. Rasband, and Kevin W. Eliceiri. 2012. NIH Image to ImageJ: 25 years of image analysis. *Nature Methods* 9, 7 (July 2012), 671–675. https://doi.org/10.1038/nmeth.2089 Publisher: Nature Publishing Group.

[9] Gabriel Marinho e Silva, José Augusto Garcia, Julia de Alencar Garitta, Davi Gasparini Fernandes Cunha, Nícolas Reinaldo Finkler, Eduardo Mario Mendiondo, and Filippo Ghiglieno. 2022. Smartphone-based spectrometry system as a prescreening assessment of copper and iron for real time control of water pollution. *Journal of Environmental Management* 323 (Dec. 2022), 116214. https://doi.org/10.1016/j.jenvman.2022.116214

[10] Kevin Vo. 2013. 2.1.5: Spectrophotometry. https://chem.libretexts.org/Bookshelves/Physical_and_Theoretical_Chemistry_Textbook_Maps/Supplemental_Modules_(Physical_and_Theoretical_Chemistry)/Kinetics/02%3A_Reaction_Rates/2.01%3A_Experimental_Determination_of_Kinetics/2.1.05%3A_Spectrophotometry

[11] Li-Ju Wang, Yu-Chung Chang, Xiaoxiao Ge, Allison T. Osmanson, Dan Du, Yuehe Lin, and Lei Li. 2016. Smartphone Optosensing Platform Using a DVD Grating to Detect Neurotoxins. *ACS Sensors* 1, 4 (April 2016), 366–373. https://doi.org/10.1021/acssensors.5b00204 Publisher: American Chemical Society.

Received 4 September 2024; revised 27 September 2024; accepted 3 October 2024