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Measurement of Photon Diffusion with Mobile Phone Camera with Appications to mHealth Monitoring

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***Abstract*—The project studied the photon diffusion through turbid media with mobile phone camera. The student experiments in transmission profile imaging and pulse broadening measurement were calibrated with the same samples used in published research papers. Light sources employing He-Ne laser and consumer product keychain LED were included in the project. Application to mHealth monitoring was demonstrated in the measurements of an index finger diffusion mean free path and the embedded blood vessel absorption effect. Extension to an iris response measurement was also demonstrated. The interdisciplinary project has been popular among engineering students and engineering technology students and will be a good model project for future students.**

Keywords*— Photon diffusion; turbid media; mHealth monitoring; mobile phone camera; iris response; index finger diffusion property; blood vessel absorption effect

I. INTRODUCTION

The development of mobile technology has produced apps that can track physiology markers such as heart rate, etc. and the mobile health technology market is expected to exceed $8 billion by 2018, according to research company GlobalData [1]. The predicted growth has been attributed to the needs in the monitoring of fitness, nutrition and diagnostic imaging data [2]. FDA has extended its regulatory power to include medical mobile apps [3] and the final guidance was issued Sept 2013 [4]. This interdisciplinary project focuses on the use of mobile phone camera as a diagnostic tool for mHealth monitoring applications.

Since most biological samples are turbid media, the study of light scattering has usually required the techniques in light diffusion measurement. The diffusion comes from repeated small angle forward scattering related to Mie scattering as well as from large angle scattering arising from sub-micron internal structure. By analyzing light diffusion in transmission using the spatial profile calibrated to pulse broadening data, information on the mean free path, absorption and refractive index can be obtained [5, 6]. Although the forward light scattering from cells in suspension has been the traditional method for the determination of cell size via the Mie theory, additional results have established the importance of large angle signal as arising from the internal sub-micron structure and that cell size has little contribution to light diffusion data [7]. Therefore photon diffusion would be useful as a diagnostic tool at millimeter and multiple-micron level. A monitoring tool needs baseline data and deviation would be used as an alert.

Community college pre-engineering students need counseling on which career path such as electrical engineering, chemical engineering, environmental engineering, biomedical engineering, etc. Hands-on experience gained in doing a research project in a laboratory and presenting the results in conferences would enhance motivation and improve retention. This interdisciplinary project carries an added education value for showing a student the difference between an engineering program and engineering technology program in a community college. The measurement of photon diffusion involves instrumentation and calibration usually found in an engineering setting. The deployment of the associated mobile apps using software packages such as LabView can be found in an engineering technology program setting. This report emphasizes the photon diffusion instrumentation and calibration.

II. MATERIALS AND METHODS

The light sources used in the project were mobile phone light source, keychain LED, and room light. The detectors are iPhone and Android cameras for measuring photon diffusion transmission. The student pulse broadening experiment was conducted with a nitrogen dye laser with 3-ns pulse width in the visible wavelength range. The 3-ns pulse broadening data has been verified using a faculty pulse broadening experiment equipped with a mode-lock visible pico-second laser [8, 9]. The calibration samples are alumina, nylon, and consumer product bottle cap. The applications to mHealth monitoring have been explored using iris response and index finger light transmission data. The NIH free software ImageJ has been used by us to extract changes in the lightcurve data during exoplanet transit observed in our college observatory [10]. The use of ImageJ extraction algorithm on mobile phone camera data has been a simple extension for our community college students. Data analysis work has been done with LabView, MAPLES, Matlab, and Visual Basic in Excel environment, as each student has learned from his/her previous STEM courses. The transmission data were fitted with the profile solutions that were published in Reference 9 (available online for easy reference of the data fitting procedure). A traditional 2-dimensionl random walk simulation has been used in fitting the pulse broadening data with diffusion parameters [11].

III. RESULTS OF DATA ANALYSIS

The raw transmission profiles of a 6-mm nylon slab are shown in Figure 1 with He-Ne and keychain white LED sources.

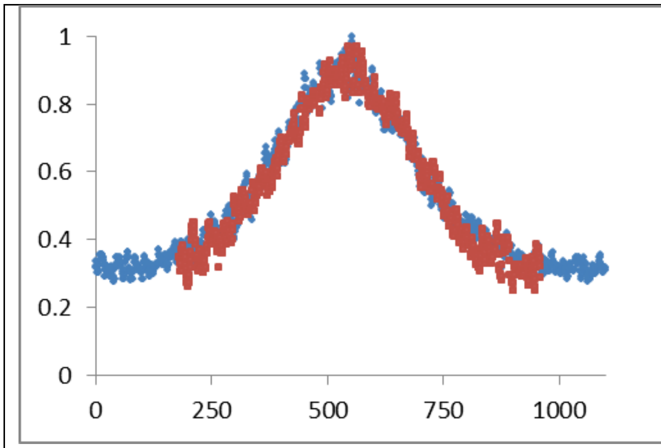

Figure 1: Raw transmission signal (y-axis arbitrary unit) versus camera pixel (x-axis 15-micron per pixel resolution) of a 6-mm nylon slab with a mean free path of about 80 microns. The diamonds represent data using a He-Ne laser and the squares represent data using a keychain LED. The LED source touched the slab in the experiment.

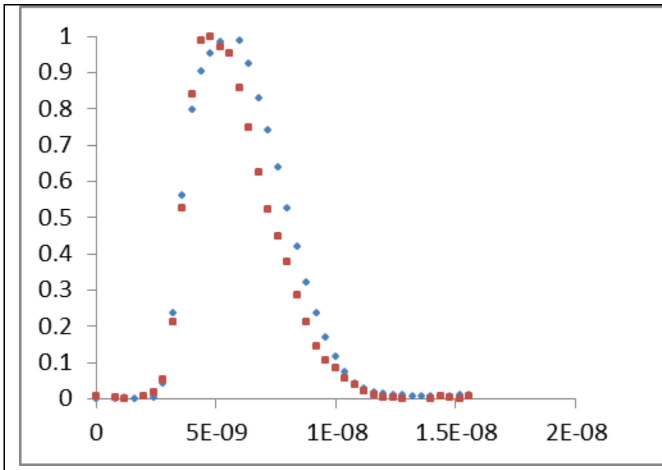

Figure 2: The pulse broadening data of the 6-mm nylon slab used in Figure 1 experiment with x-axis as time in seconds. The use of 80-micron mean free path value would fit the profile (diamonds) after de-convolution from the instrumentation pulse (squares)

The speckle fluctuation were averaged out in multiple scans and modeling fitting using the solutions in Reference 9 yielded a mean free path of about 80 microns, which would fit the pulse broadening data shown in Figure 2. The thick sample randomizes the input light source such that the two transmission profiles in Figure 1 show similar values in width. The LED larger width effect has been studied with two other experiments. A consumer product bottle cap (Rite-Aid folic acid bottle cap in white) as sample would yield different profile width when illuminated with He-Ne laser (Figure 3) and keychain white LED (Figure 4). The narrower spatial diameter from the He-Ne laser has yielded a narrower profile width. The effect of the input beam width can be visualized clearly when the sample used was a thin alumina slab (Figure 5). The used alumina sample had been measured and reported in References 7 and 8. The measured 31-micron mean path value in the alumina slab has been used as calibration.

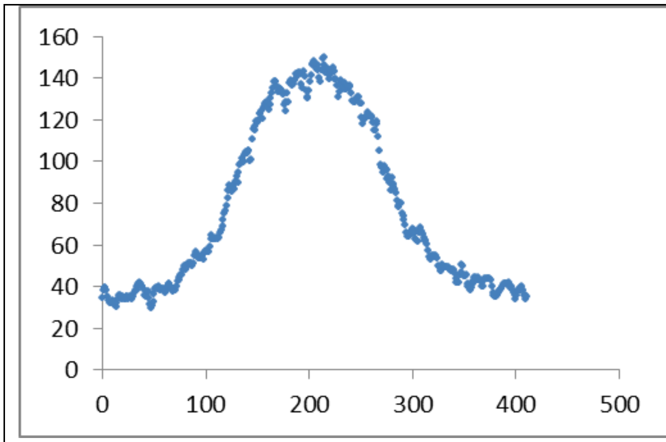

Figure 3: Raw transmission signal (y-axis arbitrary unit) versus camera pixel (x-axis 15-micron per pixel resolution) of a white bottle cap with a mean free path of about 50 microns under He-Ne laser illumination

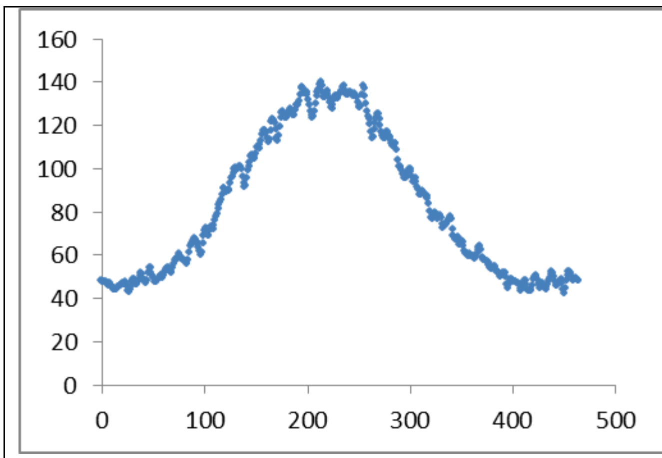

Figure 4: Raw transmission signal (y-axis arbitrary unit) versus camera pixel (x-axis 15-micron per pixel resolution) of a white bottle cap with a mean free path of about 50 microns under keychain white LED illumination.

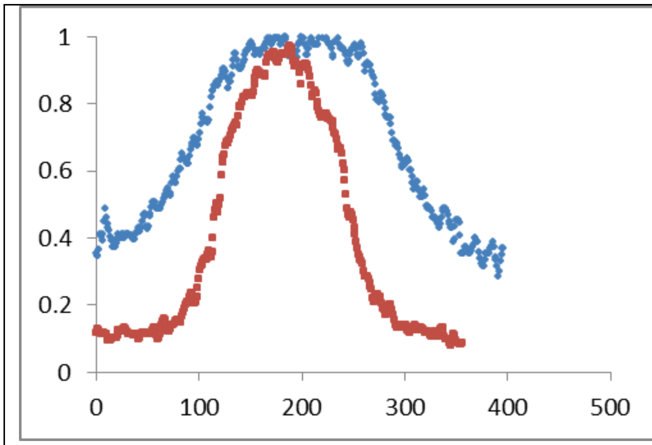

Figure 5: Raw transmission signal (y-axis arbitrary unit) versus camera pixel (x-axis 15-micron per pixel resolution) of an alumina slab used in References 7 and 8. The broad profile represents keychain white LED illumination. The more narrow profile (squares) represents He-Ne laser illumination.

IV. DISCUSSION

It is clear that mobile phone camera has the capability to measure transmission profile for the extraction of mean free path information. A transmission image using keychain white LED illumination is shown in Figure 6 where the blood vessel inside an index finger was detectable. The corresponding data profile is shown in Figure 7.

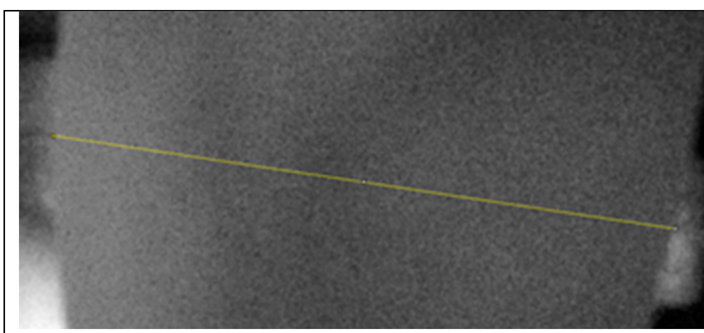

Figure 6: Raw transmission image using keychain white LED illumination on an index finger of a faculty co-author. The line was inserted by ImageJ in the data analysis process.

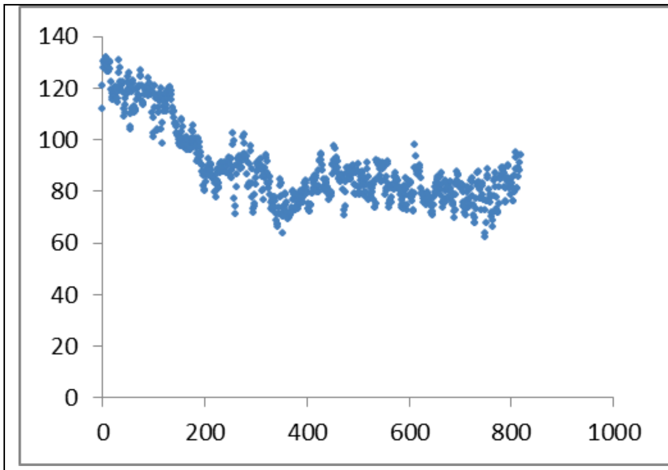

Figure 7: Transmission signal (y-axis arbitrary unit) versus camera pixel (x-axis 1.83 cm across) of the image shown in Figure 6. The blood vessel regions correspond to pixel numbers from 200 to 245, and 340 to 400.

A diffusion mean free path range of 150 to 200 microns and an absorption effect range of 10% to 20% for the blood vessel would fit the data within 25% uncertainty using a random walk model that treat the finger as a 1.2 cm uniform slab. The data quality did not warrant a tight parameter fitting, but the principle of detection has been demonstrated. The blood vessel absorption analysis and tissue transmission diffusion would be useful for tracking physiology in future studies. Whether it is necessary to have a better wavelength filter for live mHealth diagnostic application would be worthy of future studies.

The iris response to room light excitation has been measured using the video mode. The current apps on iris monitoring using iridology chart interpretation for diagnostic purpose could be classified as pseudoscience. However the iris response measurement is a valid scientific investigation. A representative image of an iris is shown in Figure 8 and one of its digitized profiles is shown in Figure 9. The small bright region near the iris edge was used as position calibration for all other image frames. The relative percent difference of the iris width between low and bright illumination conditions would not be affected even when the digitization was slightly off the iris center. A switch-on of about 3 times the illumination had an effect of narrowing the measured iris width by about 20% in 2 sec for the eye of a 60 years old faculty co-author. Future studies could include dedicated apps development for optimum data collection in the monitoring of iris response with physiological parameters.

The overall education value of this project can be quantified by tracking the student success rate in graduation and job satisfaction after transferring to a 4-yr degree program. The iris response project has enhanced education value to show the students that pseudoscience procedure would be still amenable for scientific refinement and investigation. Our community college is located within New York City and our Borough of Queens has students speaking over 100 languages as their mother tongues with diverse cultural backgrounds. Many of our students are first generation college students and the obstacles associated with pseudoscience concepts would be eliminated in projects sharing the same scientific spirit of this iris response measurement project.

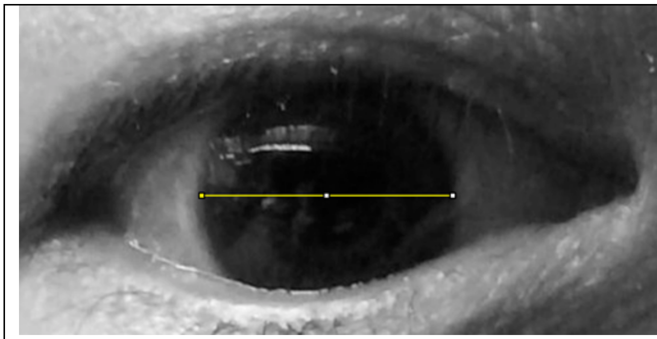

Figure 8: Raw eye image using low room light illumination (camera flashlight was not used). The line was inserted by ImageJ in the data analysis process. The small bright region near the iris edge was used as calibration for all other image frames. The percent difference of the iris width between low and bright room light illumination conditions would not be affected even when the digitization was slightly off the iris center.

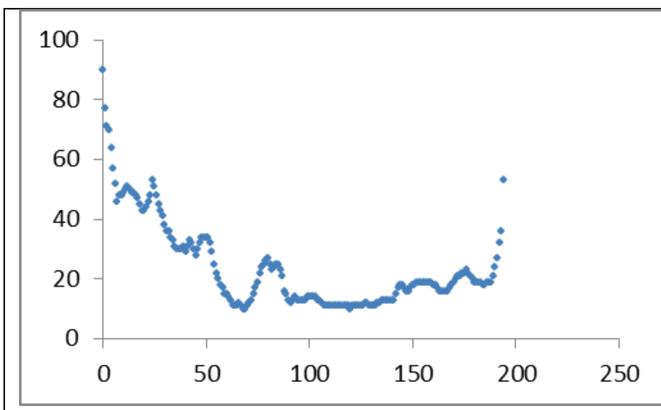

Figure 9: Signal (y-axis arbitrary unit) versus camera pixel of the image shown in Figure 8. The iris corresponds to pixel numbers from 52 to 144.

V. CONCLUSIONS

The project studied the photon diffusion through turbid media with mobile phone camera. Application to mHealth monitoring was demonstrated in the measurements of an index finger diffusion mean free path and the embedded blood vessel absorption effect. Extension to an iris response measurement was also demonstrated. Future collaboration with industry with student internships would be possible. The interdisciplinary project has been popular among engineering students and engineering technology students and will be a good model project for future students.

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