Beyond the current Smartphone Application: Using smartphone hardware to measure UV radiation

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Abstract. Smartphone applications that predict UV radiation exposure are evolving in ways to assist the user in determining how much protection from exposure to UV radiation should or might occur. The usefulness of these apps are apparent, yet many do not harness the entire range of capabilities of a smartphone. Research performed at the University of Southern Queensland has been investigating the use of a smartphone in different ways to support new or improve current applications. Smartphones have been shown to detect UVA radiation, and more recently UVB radiation. A review of the advances, and limitations of smartphones will be presented, including consideration of where to go from here.

Introduction

Smartphone applications (apps) are an interactive way to encourage the public to review and manage their UV exposure individually. Smartphone UV apps function by a number of different ways, including obtaining data from local weather stations to predict UVI (eg., Sunsmart, Cancer Council Victoria & VicHealth), using algorithms to predict UV irradiance from image capture (Mei et al. 2015), connection to an external device that measures UVI or UV irradiance (UV Sense, L'Oreal; (Cooper 2018)), or image capture of an external based sensor (My UV Patch, L'Oreal & La Roche-Posay). The UV research group based at the University of Southern Queensland have been focusing on using internal smartphone hardware to measure and collect UV irradiance measurements in order to progress the development of smartphone apps devoted to UV exposure measurement for individuals. The focus on using internal hardware reduces the need to rely on internet access for the smartphone to access external weather stations, and attempts to reduce the need to purchase additional items to use in conjunction with the smartphone that may increase costs to users. Or more simply, to reduce the need for a device that could be forgotten to be carried alongside the smartphone. There are a number of key aspects to using internal hardware of the smartphone for UV measurement, which will be discussed here, as well as limitations. Progression of the capabilities of existing internal hardware means efficacy of smartphone app technology for personal monitoring of solar ultraviolet radiation will likely improve.

Smartphone Detection of UVA radiation

Different smartphone models have been shown to detect and evaluate narrowband UVA (wavelengths between 320 nm-400nm) radiation (Igoe & Parisi 2015) without removal of any hardware from the smartphone camera surrounding the CMOS sensor. The process requires the use of narrowband and neutral density filters to isolate the wavebands of interest that are detected by the smartphone CMOS sensor. Additionally, the data collected from narrowband information can be used to reconstruct the broadband UVA radiation.

Smartphone Detection of UVB radiation

For smartphone internal hardware to be useful to estimate biologically effective UV exposure, the CMOS sensor must also be able to detect direct UVB radiation (280 nm- 320 nm) due to the waveband's impact on biological systems. Research has shown that smartphone hardware is able to detect UVB radiation across the entire waveband and demonstrate variation in photon energy detection with removal of an outer protective filter (Turner et al. 2017). Further research has since shown that smartphone CMOS sensors can detect direct UVB radiation without removal of smartphone filter hardware (Igoe et al. 2017), with detection of 305 nm corresponding to varying air masses. This research has since been extended to be used to extrapolate ozone column measurement using a smartphone sensor (Igoe et al. 2018).

Recent data in smartphone UV detection

Figure 1 provides data showing information derived from captured images, restricted to the detection of direct specific wavelengths of 305 nm, 312 nm and 320 nm. The captured images are collected for a range of solar zenith angles and varying air masses. After image analysis, which uses chromatic and digital information analysis run by a Python script, the direct irradiance ($I_{\text{smartphone}}$) can be calculated from derived functions that relate the digital information to solar irradiance. The derived function of the uncalibrated smartphone data is:

$$\ln I_{smartphone} = \ln(RD^2 \cos^4 \theta_{SZA})$$

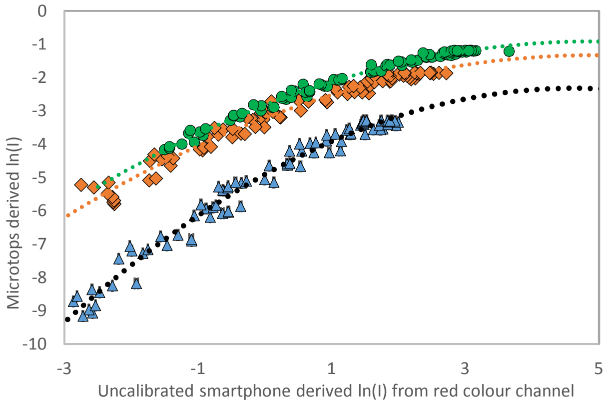

Figure 1. Green circles – 320 nm, orange diamonds – 312 nm, blue triangles – 305 nm. The derived direct UV irradiance for each wavelength is compared to the direct UV measured irradiance from a Microtops II (Solar Light Co., PA, USA).

where R is the red channel signal, D^2 is the Earth-Sun distance factor[1] and $\boldsymbol{\theta_{SZA}}$ is the solar zenith angle. There is a noticeable difference between the relative position of the derived irradiance values between the 312 nm and the 320 nm wavelengths compared to the relative position of the 305 nm and 312 nm wavelengths. This is potentially due to the FWHM of the 320 nm bandpass filter (10 nm) as compared to 2 nm for the 305 nm and 312 nm filters. Additionally, the parabolic function produced between the measured and derived irradiances, appears to become shallower as the wavelength increases. This is reasonable, as previous work has shown this calculated function progresses linearly for wavelengths of 340 nm and 380 nm, however this was achieved with a different smartphone (Igoe et al. 2014).

Limitations to use of smartphone hardware

The limitations to the current work carried out by the authors show that whilst smartphone hardware (such as protective filters or covers) does not need to be removed in order to detect UV radiation for research purposes, the smartphone does however require a number of filters to enable the smartphone to detect specific wavelength ranges when exposed to broadband UV radiation. For some research, only one to two narrowpass filters are required, along with light leakage prevention. The filters are attached to the smartphone via neodymium magnets. In some cases, additional neutral density filters are attached in order to prevent saturation of an image.

New research investigating detection of broadband UV radiation with broadband filters shows that the filters are good at preventing transmission of visible radiation, but are not capable of preventing infrared (IR) transmission reaching the sensor. IR radiation may interfere with detection of UV radiation (Tetley & Young 2008). Therefore an additional IR absorbing filter is required. It is difficult to obtain a filter that can prevent IR transmission but allow UV transmission (specifically UVB radiation). Broadband UV sensing additionally requires neutral density (ND) filters. Most ND and bandpass filters in the UV spectrum are reflective. This would normally not be a problem, however stacking multiple reflective filters to achieve the desired transmission, produces reflections within the image captured and can influence pixel data analysis when not accounted for (Figure 2). Current work uses detection of a single direct image of the sun to correlate with the UV irradiance.

Organisation of the filters within the filter stack will reduce the number of recorded reflections. If there is more than one reflective ND filter, it is difficult to remove all internal reflections in a compact way that does not create large external objects to the smartphone. A single ND filter would be ideal but commercially is not available for the requirements in the current project. A custom filter holder would be required to re-orient filter stacks to prevent reflection capture in the image. Smartphone camera stability can also be an issue causing blurring, although it could be equally due to photon "spill", an effect that is sometimes seen with saturated sections of an image, in that photons from the saturated section move into surrounding pixels that are not saturated.

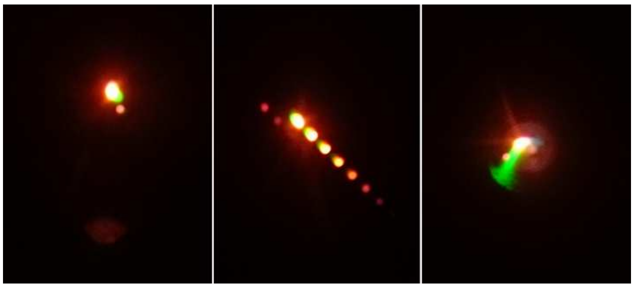

Figure 2. Examples of internal reflections through filter stacks. Lack of camera sensor stability may have contributed to false colour blurring. It may also be due to saturation, where maximum photon irradiance prevents further detection and sometimes causes a "spill" of photons into neighbouring pixels.

Conclusions and Future Directions

Smartphone internal hardware has been used for ultraviolet radiation detection and measurement with success. For now, this could not be employed for use by the public due to the additional cost and complexity of the current process. The future direction of research must continue to characterise CMOS sensors for UV irradiance detection, but will have to establish how to measure personal UV irradiance or exposure from non-sun normal methods, and calibrate individual smartphones, for this to become user friendly to the public.

Erratum

Please note in versions downloaded prior to 17 June, 2018, there was an error in the labelling of Figure 1, where the legend values for 305 nm and 320 nm were incorrectly provided. This has been corrected.

References

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[1] The Earth-Sun factor normalises the colour channel response to mean Earth-Sun distance and is independent of wavelength. The model was found to require this factor (Igoe et al., 2018). The model was compared to ozone measured by the Microtops II (Solar Light Co., USA) which automatically accounts for the changes in irradiances due to Sun-Earth distances, whereas the smartphone does not (Microtops manual).