Comparative signal to noise ratio as a determinant to select smartphone image sensor colour channels for analysis in the UVB

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The signal to noise ratio (SNR) is an important consideration for any scientific image sensor application, particularly the relatively low light involved with observations of the solar disc at a discrete ultraviolet-B (UVB) wavelength using an unmodified smartphone image sensor. In particular, the SNR of each of the primary image sensor colour channels (red, green and blue) is a critical step in determining which colour channel signal to analyse for any characterisation research. In each image, the solar disc appears as a very small pale-magenta dot. In this paper, the SNR of each colour channel response for solar UVB, alongside their chromatic transforms were analysed for a stacked, mosaic filtered, backside illuminated complementary metal oxide semiconductor (CMOS) image sensor. Using data visualisation techniques, it has become clear that specific colour channels, in this case – the red channel, provide the strongest SNR for use in characterisation and other analytical research. The effects of a straightforward adaptive threshold and de-noising algorithm (median filter) on each colour channel's SNR are also analysed. The variation of the colour channels' SNR with external factors, including irradiance, is modelled. The effects of the prevalence of noise features, such as hot pixels and dark noise, are also observed. It has been found that before the median filter is applied, most of the signal, particularly for the green colour channel, is from these noise features in some image sensors – representing a 'false positive' in these low-light conditions. A chrominance model using a weighted proportion of the red and blue colour channels that provides the best SNR when sensing in the UVB waveband for the sensor has been developed and evaluated.

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1. Introduction

The increasing ubiquity of smartphones in everyday use provides a low cost and accessible tool for many scientific studies [1–5]. Recent applications that use smartphone image sensor technology for fine detailed analysis include solar ultraviolet (UV) and aerosol optical depth measurements [6], ultraviolet B (UVB) characterisation [1,7], air quality monitoring [8], water quality testing, for salinity [9], turbidity [10], fluoride [11] and mercury content [12], medical microscopy [13] and biosensing platforms [14]. Some of these applications employ smartphone imaging sensors or cameras. Previous research has determined that smartphone sensing, particularly in the UV, rely on spectrometer-based approaches for imaging beyond colorimetric transforms [15]. Smartphone cameras have an increasing number of pixels, resulting in an increase in resolution, but at the cost of smaller pixel sizes, contributing to less photons reaching each pixel. This can potentially cause an increase in sensor noise, including pixel crosstalk [2,5,16].

The signal to noise ratio (SNR) is a physical measure of the imaging system sensitivity and relative proportion of the noise in the image signal [17,18]. The SNR values for each smartphone image sensor colour channel have previously been evaluated during the calibration phase of earlier field research for characterisation to solar UVB (280–320 nm) after a median filter was applied [1]. In low light conditions, the addition of the UVB narrowband filter for measurements in the UVB waveband induces greater occurrences of impulsive noise, such as 'hot-pixels' that are likely to occur in a resulting image [4,19]. There are a number of mechanisms that cause noise including object bidirectional reflectance and anomalies within the electronics of the image sensor itself [18], for applications such as UV imaging of the sun, previous observations determined that some diffuse radiation is still captured by the image sensor, contributing to the noise [1]. These are important and commonly occurring considerations for image sensors with small pixel sizes and spread during the image processing pipeline.

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Pixel degradation, resulting in defects such as hot-pixels, increases in occurrence over time as the sensor ages [2]. To overcome these defects, a median filter has previously been applied to remove anomalous ‘hot pixels’ in an earlier characterisation to the solar 305 nm wavelength [1].

The colour channel SNR values have been determined using the ‘20log’ rule [17,19,22]. This rule uses 20log of the SNR ratio of the mean image pixel value minus the background (‘dark’) signal to the standard deviation of the pixel value, measured in decibels (dB) [17,19,22,23]. The 20log rule is included as part of an industry standard by the European Machine Vision Association Standard 1288 [17,24].

Smartphone image sensors typically do not follow the standard Additive-White Gaussian Noise (AWGN) model, as the noise standard deviations are not constant [4,5,19,25]. A SNR of approximately 32 dB is considered to indicate that the image is of excellent quality, and 20 dB is an indicative of ‘acceptable’ quality. The ‘Rose Criterion’ is a semi arbitrary boundary for which it is said that the image can be discernible from the background noise, at an SNR of 5 – a criterion that has been used in many optics based applications [23,26]. The strong ambient temperature dependence that affects the dark noise present in image sensors has previously been found to be a negligible factor [7,19,27].

Images are typically stored as the default JPEG file format on smartphones, although recent research has performed significant modification on the smartphone to retrieve RAW image data [28]. From an unmodified smartphone, JPEG compression noise tends to have a lower frequency component, more prominent in the chrominance channels (based mainly on the red and blue colour channels) rather than the luminance channel (based mainly on the green channel) [5]. Previous observations by Igoe et al. [1] found that in low illumination in the UVB waveband, the green colour channel possessed the greatest proportion of noise relative to the signal. This suggests that JPEG compression is also not a significant contributor causing the overall noise observed in smartphone images.

When using smartphones (or similar technology) for measuring in the UVB [1,7], it is important to gauge the integrity of each of the

Fig. 2. a. SNR of the red (black circles), green (black triangles) and blue (grey squares) from unmodified images compared to the air mass. b. SNR of the red (black circles), green (black triangles) and blue (grey squares) from unmodified images compared to the solar UVB irradiance at 305 nm.
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