Effects of Smartphone Sensor Characteristics on Dermatoscopic Images, a Simulation Study.

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ABSTRACT

Dermatoscopes are commonly used to evaluate skin lesions. There are a wide array of medical imaging devices entering the market, some of which allow patients to analyze skin lesions themselves. These devices usually come in the form of smartphone attachments that leverage smartphone optics to acquire images; and in some cases, even give a preliminary diagnosis. While these attachments are useful, smartphone sensors are small which limits the extent and detail of captured images as opposed to images from a professional camera.

Our work focuses on the information lost due to the known limitations of smartphone sensors, and its effect on image appearance. This analysis has been performed using a virtual simulation pipeline for dermatology, VCT-Derma, which contains simulated skin and dermatoscope models, among others. We discuss the necessary sensor parameters to adapt the dermatoscope model to various sensors, and with the help of the skin model and a colorgauge chart, obtain images from the sensors simulated.

Results indicate differences in image clarity as well as observed color fidelity between the reference dermatoscope and smartphone sensors. Results of imaging the skin model show improved feature clarity in the reference device image as compared to the two smartphone sensors. Results of imaging the colorgauge chart show average $\Delta E2000$ values of ~12.5 across all color patches for the reference device, and smartphone sensors. Under the same lightning, smartphone sensors showed areas with saturated pixels, as opposed to the reference device. Research is ongoing on the influence of multispectral illumination on these sensors.

Keywords: Camera, Virtual Clinical Trials, Smartphone, Dermatoscopy, Simulation.

1. INTRODUCTION

Dermatoscopy is a non-invasive method of skin imaging in which dermatologists utilize devices called dermatoscopes to diagnosis skin lesions. While these devices are predominantly analog in nature (making use of a light source and magnifying lens essentially), recent years has seen a steady influx of digital dermatoscopes. These digital dermatscopes range from large imaging systems, to handheld devices, to even smartphone attachments and applications[1]. The latter is the focus of our current work.

These smartphone attachments provide the user/patient with the ability to monitor their own lesions. Many attachments come with an accompanying application that give a preliminary diagnosis on the severity of the lesion. The applications are aimed to reduce the burden of having to visit a dermatologist multiple times if a similar diagnosis could be achieved from one's own home. Although useful, the image sensors in smartphones have a limited amount of information which they can process and output to the user. Moreover, smartphone sensors are very small which limits the extent and detail of the captured image as opposed to dermoscopy data acquired by a professional camera system.

It is a known fact that most displays and camera devices apply calibration and image processing to the image. This is especially true in case of smartphones, in order to make the resulting image more appealing to the user. To that end, it is very important to ensure that the digital image of the lesion that is viewed by the dermatologist is as close to the original appearance of the lesion as possible. Lesion color is most to be affected by such processing, which may affect the resulting diagnosis.

The sensors in question were part of an earlier publication that analysed their spectral and radiometric calibration[2]. That publication provided the spectral characteristics of the sensor needed for our simulation. Such information is generally proprietary, and not available to the public unless measured explicitly. The available spectral properties allowed to also analyse the color of the resulting image. Some contemporary devices employ multispectral lighting[3] to provide additional information to the dermatologist. Our future research includes comparing the performance of devices with multispectral lightning vs. smartphone attachments.

Our work in this manuscript is focused on the information lost due to the known limitations of smartphone sensors, and its effect on the image appearance. This analysis has been performed using a virtual simulation pipeline for dermatology, VCT-Derma[4]. The pipeline contains a module for the simulated dermatoscope whose optical stack parameters will be adapted to the smartphone, and reference device, sensor specifications, as detailed in Section 2.2.

This manuscript also describes the necessary sensor parameters required for adapting the simulation model, the software used along with any assumptions made, perceived differences in the resulting images, as well as the direction of the ongoing work.

2. METHODOLOGY

2.1 VCT-Derma

The VCT-Derma[4] pipeline consists of simulation modules which replicate an entire digital dermatoscopy pipeline including both the image acquisition and image processing components of the dermatoscope[3]. A CAD model of a reference dermatoscope (proprietary) has been imported into Blender[5]; a 3D modelling tool that gives the user the ability to assign material configurations to the various parts of the device based on their real-world materials. This allows us to consider virtually all major internal reflections and other phenomena that may affect the image quality. This will be expanded in section 2.3. More details regarding the VCT-Derma pipeline can be found in our earlier publication[4]. This model of a reference dermatoscope will serve as our reference device for the tests to come (detailed in Section 2.3)

2.2 Smartphone Devices

We have simulated two commonly used smartphone sensors (hereafter referred to as sensors X and Y), which differ in their acquisition parameters: spatial resolution, sensor and pixel size, chroma, f-stop and focal length (see Table 1). These sensors were chosen based on the availability of material and information. Smartphone sensor data, outside of what's mentioned in Table 1 is proprietary to the smartphone manufacturer. The sensors selected have been part of a previous report[2], the measurements of which have proved useful in preparing this manuscript. These smartphones have been selected because of the popularity of their respective brands in the smartphone market.

Generally, smartphone sensors tend to be much smaller than the full-frame (36mm x 24mm) 35mm-equivalent. Consequently, this requires that the sensor focal lengths be in the range of 4-6mm, which results in a broader field of view, but reduced magnification. 35mm-equivalent focal lengths as defined as the focal length the camera's lens would need to have if it were to produce equivalent images on a DSLR with a 35mm-format sensor. Making use of 35mm-equivalent focal length for the selected sensors provides a sufficient crop factor[6] / magnification to allow for a fair comparison between them.

Today's smartphones tend to have more than a single camera sensor, so we have focused on the primary camera sensor alone in our measurements and tests. This is because the other camera sensors tend to be ultrawide, used for capturing large scenes. The relevant specification parameters of each sensor are summarized in Table 1. It should be noted that the effect of polarization is not included in our tests (more details on this is Section 2.3).

Table 1 - Smartphone Sensor Characteristics

Name	Sensor Spatial Resolution	Sensor Size	Pixel Size	Chroma	f-stop	Focal Length	Crop Factor
Reference device	3864 x 2202 8.51MP	7.20mm (1/2.5")	1.62μm	RGB	f/3.7	57.6mm	6.0
X	4032 x 3024 12.2MP	6.15mm (1/2.93")	1.22μm	RGB	f/2.2	29mm	7.2
Y	4032 x 3024 12.2MP	7.06mm (1/2.55")	1.4μm	RGB	f/1.7	26mm	6.1

In this study we have focused on the simulation and analysis of the effects of the optical stack, without considering any smartphone specific image processing as these are typically proprietary processing and the lack of available information would prevent fair comparisons.

2.3 Blender Simulation Environment

Blender[5] is the software of choice for the gauging the effect of varying smartphone sensor characteristics. We have run two tests, the first of which employs a simple setup consisting of a camera, a uniformly distributed ambient source of light and the VCT-Derma skin model[7]. The ambient light source is the default "Sun" light source that is available in Blender. This is a perfectly white source of light. The generic camera model has been modified based on the parameters mentioned in Table 1. Our skin model consists of a lesion as well as blood vessels. The skin model has been modified to negate the effect of specular reflection. This has been done by selecting the appropriate material within blender to represent the stratum corneum and epidermis layers of the skin[7]. Some dermoscopic features (blue white veil, globules) have been inserted[8] into the lesion to help analyse the images from the standpoint of a dermatologist.

Smartphones tend to apply processing by default to make the image not only visually pleasing to the user but, unless specified /or set in manual mode, also compress the resulting images. The reference device on the other hand was built with the single purpose of imaging lesions, and any enhancements / image processing made to the image such as contrast enhancement etc, are done with that purpose in mind. Smartphone specific image processing is proprietary, as is the processing done on the reference device, therefore processing of any kind will not be considered in our tests. This allows for a fairer comparison. Based off the specifications in Table 1 alone (f-stop[9] value for example), we can see that there will

be a difference between the sensors; greater the f-stop number, smaller the aperture, resulting in darker images, and vice versa.

The second set of tests run look to analyse the color fidelity of the sensors. For this we have made use of the spectral characteristics of the color filters they employ based on the results from literature[2]. A ColorGauge nano chart[10], a professional grade miniaturized target consisting of 30 pigmented color patches, has been employed. The spectral properties of these chart patches are known. The chart is used for device calibration and is only 17.5mm high x 20.6mm wide x 1.5mm thick (11/16" x 13/16" x 0.060"), while the patches are matte to prevent specular reflection. An image of the chart can be seen in Figure 1.

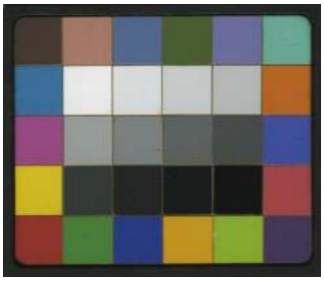


Figure 1 - ColorGauge Nano Chart (Matte finish)[10]

When it comes to dermoscopic images there are multiple factors that affect image quality, and hence the final diagnosis. In this study, we will look at how a difference in sensor spatial resolution, aperture size, focal length affects the quality, and color accuracy of the image. The resulting rendered images have been discussed in the section below.

3. RESULTS AND DISCUSSION

The images in Figure 2 has been captured under the same conditions in terms of lighting and camera positioning, with the sensor characteristics (Table 1) being the only variable parameters. Smartphone camera sensors do not generally have enough magnification to be able to pick up details of a typical skin lesion. Therefore, most dermoscopic add-ons contain a magnifying lens of some form[9] to help compensate for this issue. Most dermatoscopes tend to have a 10x magnification[9] while smartphones are in the 2-3x magnification range. The latter also tends to involve a certain component of digital magnification which is unreliable in situations where every detail can matter, and it is better to preserve details than try to use interpolation to recover the details. The images in Figure 2 originally had crop factors of ~6-7 but since we have adapted the focal length to a 35mm sensor equivalent, it allows for a much fairer comparison with the reference device.

From Figure 2, it is evident that there are differences in simulated image appearance, as observed by a naked human eye, between the smartphone sensor images and the reference image. Generally, the varying spatial resolution of smartphone sensors affects the level of detail in the images, hence a larger spatial resolution results in larger, more detailed images, improving on the chances of capturing more information while providing the possibility to crop out and focus on certain areas without compromising on quality. In Figure 2(a), sensors X and Y have the same spatial resolution of 4032 x 3024, yet the lesion from the sensor X image appears larger than the sensor Y image. This is due to the difference in focal lengths of the two sensors. A focal length of 29mm for sensor X resulted in an image which has a narrower field of view as compared to sensor Y. This is further seen when looking at the reference device image which has a much larger view of the lesion due to its much larger focal length.

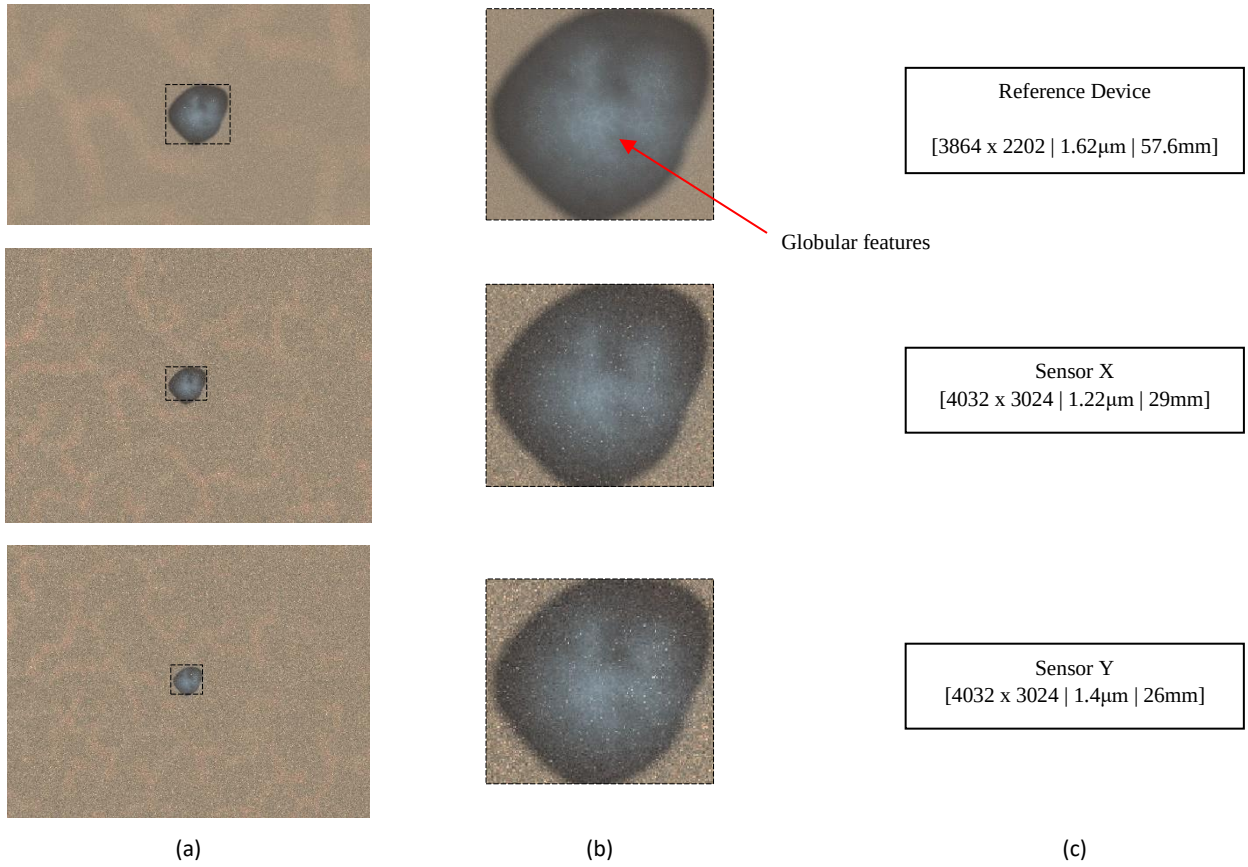


Figure 2 – (a) Simulated skin images (with marked region of interest) for three different sensors considered in the study: the reference device and two commercial smartphone camera sensors X, Y (all as described in Table 1); (b) Enlarged region of interest within the lesion to determine dermoscopic features (globules); (c) Sensor characteristics: resolution, pixel size, and focal length respectively. The parameters of lighting and sensor position/distance to the skin are the same for all sensors.

Magnification is just one of the differences between dermatoscope and smartphones, but this is not a deterrent with some smartphone attachments helping to alleviate this to an extent. The difference occurs in the size of the sensors (Figure 2(c)). The reference device has a sensor size of 1.62µm while the smartphone sensors have sizes of 1.22µm and 1.4µm. Although the reference image does show us a more zoomed in view of the lesion, its narrower field of view does tend to limit the observation of surrounding vessels (if any).

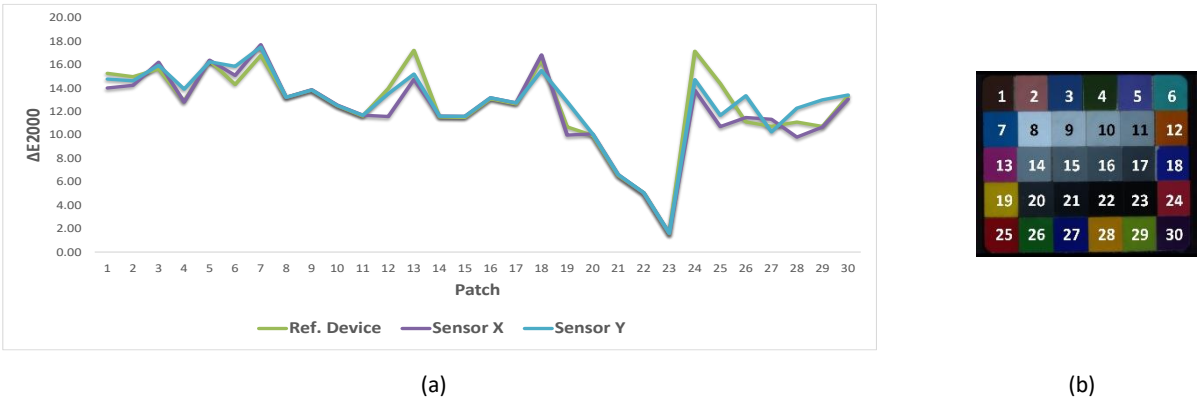
Figure 2(b) shows the presence of globular features within the lesion in the image from the Reference Device but not in the images from the Sensors X and Y. In dermoscopy, diagnosis is based on an overall view of the lesion and any / all features that are present. If a feature is not clearly visible to the dermatologist in the image, it could lead to misdiagnosis which can potentially lead to a problem. These results show that different sensor will result in the same lesion images differently, which is something a dermatologist considering images from smartphones should keep in mind.

With regards to the ColorGauge chart and the test on the sensor color fidelity, we have assumed an ambient D50 illumination under which the final comparison would be made. We have taken into account the spectral response curves of the chart patches, the camera sensors, the spectrum of the illumination (LEDS) used to light up the lesion, as well as any other material that may impact the final image viewed by a dermatologist. Here, we have used the white polarised light LED. The calculated Lab values were compared with reference Lab values of the chart that are available. We have also measured the chart ourselves and compared these Lab values with the values provided. The CIEDE2000 ($\Delta E2000$)[11]

metric used allows for a perceptually accurate comparison between two colors. The higher the ΔE2000 value the greater the difference between the colors that is visible with the naked eye. A ΔE2000 value of ~2 or less is considered to be almost indistinguishable by the eye. The ColorGauge chart used comes with reference values of the color patches provided which serve as the reference values for the below calculations. We have also measured the ColorGauge chart ourselves using a spectrophotometer in order to gauge any change in color due to ageing of the charts, and also to obtain the spectral characteristics of each color patch. The CIEDE2000 values of the three sensors, calculated with respect to the reference chart values, can be seen in Table 2 while the same has been plotted in Figure 3.

Table 2 - ΔE2000 values for the sensors and reference device, calculated with respect to the reference chart values.

Patch	**ΔE2000**		
	Ref. Device	**Sensor X**	**Sensor Y**
1	15.26	14.02	14.78
2	14.98	14.24	14.63
3	15.63	16.22	15.95
4	12.88	12.81	13.92
5	16.35	16.39	16.26
6	14.31	15.09	15.86
7	16.80	17.72	17.50
8	13.22	13.22	13.22
9	13.84	13.87	13.84
10	12.51	12.55	12.52
11	11.62	11.70	11.68
12	13.98	11.58	13.52
13	17.23	14.74	15.20
14	11.54	11.62	11.61
15	11.50	11.59	11.59
16	13.09	13.18	13.18
17	12.65	12.74	12.74
18	16.43	16.85	15.51
19	10.69	9.99	12.85
20	9.97	10.10	10.08
21	6.54	6.63	6.62
22	5.07	5.06	5.07
23	1.57	1.60	1.61
24	17.15	13.82	14.73
25	14.39	10.72	11.68
26	11.12	11.50	13.36
27	10.74	11.35	10.27
28	11.11	9.81	12.29
29	10.73	10.68	13.01
30	13.33	13.06	13.42
Avg	**12.54**	**12.15**	**12.62**
Min	**1.57**	**1.60**	**1.61**
Max	**17.23**	**17.72**	**17.50**



(a) (b)

Figure 3 – (a) ΔE2000 values for Sensors X, Y, and Reference Device when compared with the provided manufacturer chart values, and (b) ColorGauge reference chart (patch numbered)

The ΔE2000 values of all patches are on average ~12.5 across the three sensors. This is partly due to the processing of calculating the ΔE2000 which involves normalising and scaling the values to the brightest point in the chart. This brings all three sensor values to a similar range. On looking at the chart in Figure 3(a), we can see that there seems to be a significant drop in ΔE2000 values for patches 19-23, which correspond to the fourth row of patches (as seen in Figure 3(b)). Preliminary investigation suggests that this could be due to the fact that these patches are the darkest patches on the chart which could make simulating them a little easier as compared to the bright patches which have a lot more color information.

But if we look at Figure 4, it is evident that the images from the smartphone sensors (Figures 4(b) and 4(c)) are more exposed and contain several oversaturated areas compared to the image from the reference device. These over-saturated areas would result in loss of information in those respective areas. We have taken a small region of interest within the brightest patch in all three charts (the white patch). This region of interest contains 33480 pixels. We then calculate the histogram distribution using ImageJ[12], which when exported gives us the distributions seen in Figure 4 below the respective chart images. The distributions for the grey level, red, green and blue channels are shown.

From these histograms, we can see that sensors X and Y have saturated values in their blue channel while sensor Y has also saturated its green channel. The reference device on the other hand has no saturated value on any of its channels. Sensor X has around ~5% of its pixels that are at the peak 255 value on the blue channel. Sensor Y has ~99.9% of pixels saturated on the green channel and 100% of all pixels saturated on the blue channel. This shows that there is clearly information lost, with respect to the white patch measured here, in the cases of Sensors X and Y.

Other methods of comparison with respect to varying illumination (multispectral leds, varying ambient light), device ageing etc, have not been considered in this manuscript but tests on examining the impact of multispectral leds is currently ongoing.

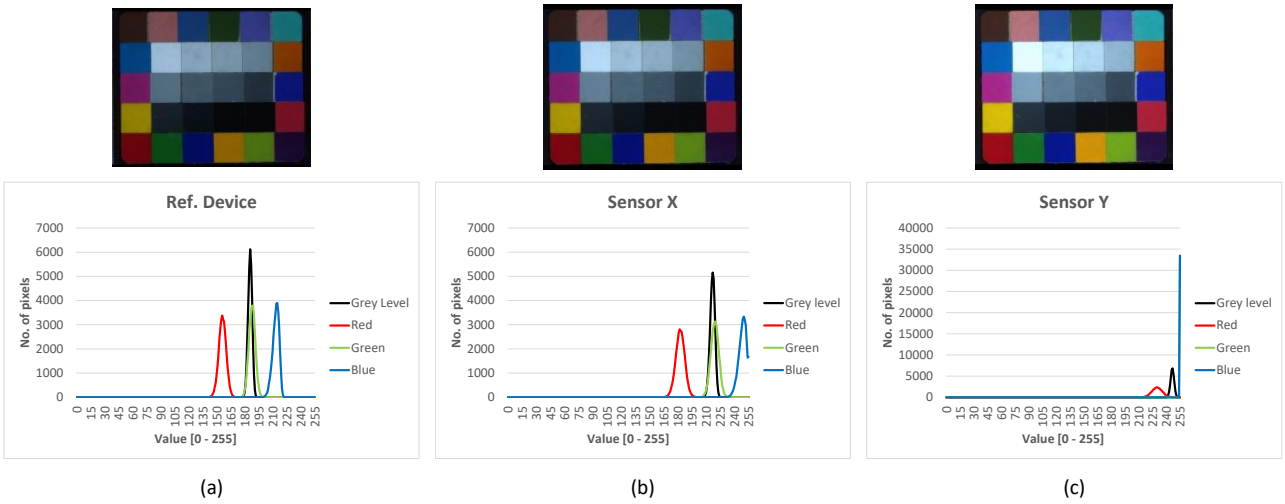


Figure 1 - The resulting chart image and histogram for region of interest within the white patch for: (a) Reference Device, (b) Sensor X, and (c) Sensor Y

4. CONCLUSIONS

There are significant differences in the characteristics of camera sensors commonly used in popular smartphones. Our project aimed at assessing the effects of sensors on the performance in dermatoscopic applications. We have used the VCT-Derma pipeline to design a virtual trial for comparing the spectral properties of two frequently used smartphone sensors and our in-house reference device. We have demonstrated that the same lesion appears differently when imaged by different smartphones. Differences in magnification and clarity of features (e.g., globular features) were evident in our VCT tests. When we simulated imaging the color charts, some colors were notably more saturated with the smartphone sensors than the reference device, leading to potential loss of information, which can be of clinical significance in dermatological applications. Work is ongoing to examine the impact of multispectral LEDS on these sensors and their images.

ACKNOWLEDGEMENTS

This work is supported by the Flanders Agency for Innovation & Entrepreneurship in the context of the Baekeland research Grant “Virtual Clinical Trials for Dermatology”, HBC.2017.0583, and the Burroughs-Wellcome Fund (IRSA 1016451).

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