

Accuracy of the skin model in quantifying the thickness of papillary dermis using colour images

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Abstract

The thickness of papillary dermis is an important parameter in optical model of the skin [1, 2]. Any change in the thickness produces different model with specific skin colouration. This paper investigate the accuracy of the skin imaging system in quantifying the thickness of papillary dermis and also epidermal melanin. It also evaluates the effectiveness of infrared primaries in contrast to conventional red, green and blue primaries for measuring the two parameters. Error analysis demonstrates that infrared primaries are more reliable for such a measurement.

Keywords: Skin Model, Melanoma, measuring the papillary dermis , infrared primaries

1 Introduction

The papillary dermal thickness affects the remitted light from the skin resulting in a change in skin colouration [3]. Since the thickness varies at different parts of the body, a reliable method is required to measure the thickness and compensate its effect when skin model analysis system [1] is employed. In real situation, the skin model is aimed to measure the level of melanin with the highest accuracy. This requires an accurate measurement of papillary dermal thickness to calibrate the model.

This report considers the sensitivity of skin imaging system to papillary dermal thickness and also the epidermal melanin for two different (extreme) levels of blood concentrations. The sensitivity of the model is also evaluated for a set of infrared primaries, as suggested by [3], and compared with the sensitivity of conventional primaries, RGB primaries.

2 Papillary dermal thickness and skin colouration

To evaluate the sensitivity of skin colouration to dermal thickness, we generate R G and B primaries for a normal skin with different levels of melanin and dermal thickness. Figure 1 shows the three primaries for two different levels of blood concentration, a very low and the highest expected level of blood concentration.

As shown in Figure 1, the effect of thickness in Red and Green primaries are very high,

especially when the level of epidermal melanin is low which is related to white people. The effect of thickness is lower as the thickness increases. The blue primary is less sensitive to the thickness when its level is higher than $0.15mm$.

The figure shows a change in the surface respect to blood level. The blood level affects the green and blue primaries more than the red. This behaviour is the result of low absorption coefficient for red primary [4].

2.1 Gradient of normal skin colouration

Comparing the absolute value of the gradient respect to a parameter with the camera noise level shows the sensitivity of the system for measuring the parameter. Here, we consider the gradient of every primary respect to melanin and the papillary dermal thickness, independently.

Let us consider partial derivatives (the gradients) of R, G, and B primaries with respect to the change in papillary dermal thickness and melanin levels; the higher the level of the gradient versus the parameter, the more sensitive the system to the parameter.

$$\frac{\delta(\text{Primary})}{\delta(\text{thickness})} \quad \text{and} \quad \frac{\delta(\text{Primary})}{\delta(\text{Melanin})} \quad (1)$$

The next section considers the gradient of each primary respect to the two parameters as compared with the sensitivity of a CCD camera with specific noise level, $\sigma = 1$.

2.1.1 Thickness of papillary dermis

Figure 2 shows the gradient of the three primaries respect to the thickness of papillary dermis. The gradients were then compared against the camera noise level.

The gradient is very high for all primaries where the thicknesses and the level of melanin are low. The low melanin level is related to people with white skin, and with the highest rate of melanoma. R primary shows a relatively high gradient for various thicknesses and melanin levels. Its level is higher than the camera noise level if the thickness is less than $0.3mm$.

The gradient level changes very rapidly for Green and Blue primaries representing a high sensitivity to the thickness. This results in a rapid saturation when the thickness increases. Saturation level for G primary is $0.2mm$. The blue, like green primary, shows

a higher sensitivity to the thickness where the level of melanin and thickness are low. A higher levels of melanin makes the skin darker resulting in a rapid saturation of the primaries and therefore lower sensitivity for higher levels of melanin. The saturation happens earlier if the level of blood is high.

Figure 3 illustrates the level of error in measuring papillary dermal thickness using our current camera, with noise level of $\sigma = 1$. As expected, the error for the red primary is almost zero for most of the range. The highest level of error is $0.03mm$ for dark skins (with high levels of melanin). Green primary can be used to measure the thickness in most of the normal cases, however with a higher levels of error than red primary where the thickness and melanin levels are high. The highest level of error for this primary is less than $0.015mm$. The blue primary shows the highest level of error in measuring the thickness. This is the result of high sensitivity to melanin and therefore a low level of remitted light.

2.1.2 Melanin level

The gradient of each primary respect to melanin level is measured for different levels of papillary dermal thicknesses, see Figure 4. Like figure 2, the surfaces are generated for two extreme levels of blood concentrations. A flat surface related to our camera noise level, $\sigma = 1$, is overlayed on the gradient surfaces. The camera noise level is used as a reference for considering the sensitivity respect to each primary.

The gradient of R and G primaries are higher than the sensitivity of camera for various levels of melanin and the thickness. The sensitivity is low where the papillary dermal thickness is low. The change in blood concentration does not have a serious affect on the sensitivity. The gradient of blue primary respect to melanin is much higher than the other two primaries where melanin level is low. The primary saturates very fast as melanin level increases which results in lower sensitivity. The effect of blood concentration is considerable for blue primary.

Using our camera, the level of error for R and G primaries is zero if the thickness of papillary dermis is not too low. In contrast, the blue primary is very sensitive to melanin level. The measurement can be performed quite accurately if the melanin level is lower than 0.01. A higher level of melanin results in higher level of error for B primary. The

effect of blood concentration is higher when measuring the melanin level is the aim. The higher the concentration of blood, the higher the level of error.

3 Total sensitivity

The total error in measuring the papillary dermal thickness and epidermal melanin concentration in a normal skin is shown in Figure 6. The figure shows contours of equal error levels for each of the two parameters when RGB primary is used for measurement. As expected the higher the concentration of melanin, the higher the level of error in measuring melanin. The figure also shows that small increase in error level is expected when the thickness is too low. The behaviour is completely different for papillary dermal thickness. The level of error increase to above zero if the thickness or melanin concentration increases.

These results show that, given an specific papillary dermal thickness, the melanin level can be measures very reliably. In contrast the measurement of papillary dermal thickness can be performed only when the level of melanin and the thickness of papillary dermis are both low.

4 Papillary dermal thickness and infrared primaries

This section considers the sensitivity of two infrared primaries, called IF1 and IF2, for measuring the thickness of epidermis. The filters for IF1 and IF2 are shown in Figure 7. IF1 responds to a wavelength rang $689 - 699\text{nm}$ and IF2 responds to a wavelength range between $935 - 945\text{nm}$.

Remitted light within the two infrared ranges are measured and their surfaces for different papillary dermal thickness and melanin are analysed. The surfaces of infrared primaries are shown in figure 8. The change of surface for various blood levels are almost zero. The figure shows that IF1 primary is sensitive to changes in thickness as well as melanin concentration, while IF2 primary is mainly sensitive to the thickness. None of the two IF primaries are saturated for the considered levels of melanin and dermal thickness.

4.1 Gradient of infrared primaries

The response of infrared primaries respect to the papillary dermal thickness and dermal melanin are more clear on gradient surfaces. As shown in Figure 9, the gradient of both infrared primaries are very sensitive to changes in papillary dermal thickness. Gradient of both primaries are mainly higher than the camera noise level. Only the gradient of IF1 is lower than the noise level where the thickness of papillary dermis and the melanin levels are too high.

5 Total sensitivity

The expected errors in measuring the papillary dermal thickness using the infrared images are computed for every level of melanin. Considering Figure 10; when IF1 is used, the expected error in measuring the thickness is zero for various levels of melanin and papillary dermal thickness. if IF2 is used to measure the thickness, an small amount of error is expected (less than 8%) where the thickness of papillary dermis and melanin levels are high.

The gradient of infrared primaries respect to melanin level shows a lower sensitivity than RGB primaries. Figure 11 shows IF1 is sensitive to changes in melanin if the thickness of papillary dermis is higher than $0.05mm$. The gradient of IF2 respect to melanin shows a very low sensitivity to melanin change. The error is marginally zero where the thickness of papillary dermis is high. This represents that IF2 is less sensitive to melanin change.

Errors in quantifying the levels of melanin is computed for both infrared images. The error surfaces are shown in figure 12. Both primaries are sensitive to melanin changes where the papillary dermal thickness is high. For lower levels of papillary dermal thickness, the error in IF2 increases rapidly while IF1 remains highly sensitive.

6 Conclusions

The performance of skin model system for measuring the thickness of papillary dermis and also the level of melanin is analysed. The error analysis demonstrates that among the R, G and B primaries only R primary has a high sensitivity to the thickness of papillary dermis. Our analysis shows that the R, G and B primaries are less sensitive to the detection of

melanin if the thickness of papillary dermis is too low. The sensitivity is lower where melanin level increases.

This report also considers the sensitivity of the system if infrared images are used to measure the level of melanin or thickness of papillary dermis. Our analysis shows that infrared images are more sensitive to the thickness of papillary dermis and less sensitive to melanin concentration. The higher the wavelength, the higher the sensitivity to the thickness of papillary dermis but the lower the sensitivity to melanin. Such behaviour makes IF2 (wavelength = 935 – 945nm) a reliable primary to measure the thickness of papillary dermis with the lowest sensitivity to any changes in dermal melanin. The maximum error caused by full range of melanin level is about 4% of the papillary dermal thickness.

The study demonstrates that the infrared primaries are more reliable than the R, G and B primaries when measuring the thickness of papillary dermis. They are more sensitive to the thickness of papillary dermis and also less dependent to the melanin level. Such a behaviour result in a more reliable measurement of the papillary dermal thickness regardless of the melanin level.

References

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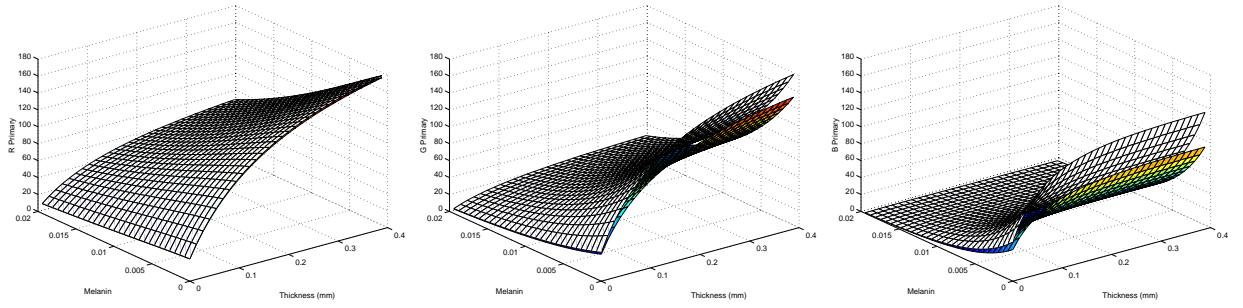


Figure 1: Red (R), green (G) and blue (B) primaries for a normal skin with different levels of epidermal melanin and papillary dermal thickness. Blood concentration is 100 and 700 for the upper and lower surfaces, respectively.

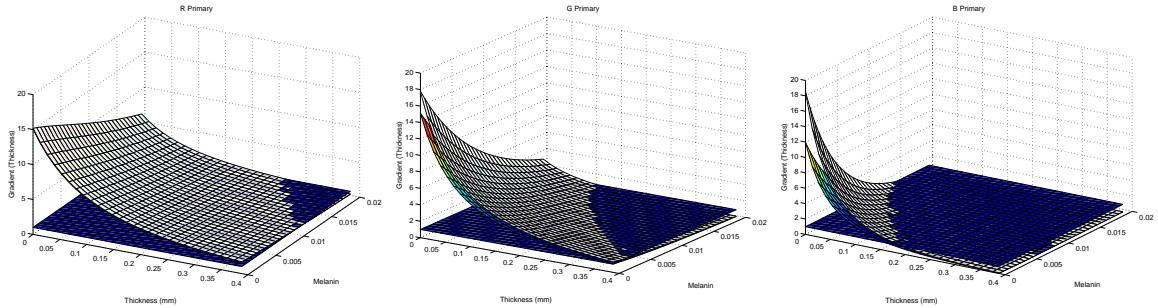


Figure 2: Absolute value of the gradient of R, G, and B primaries with respect to papillary dermal thickness. The measurement is performed for two extreme levels of blood concentrations (100 and 700).

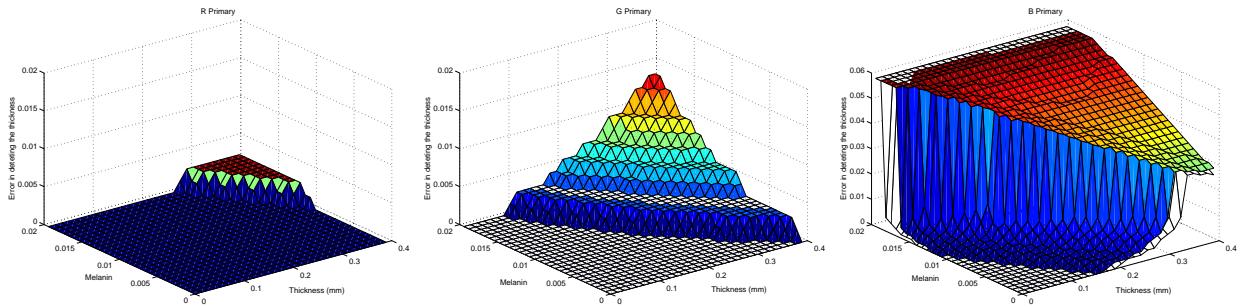


Figure 3: The error in measuring the thickness based on every single primary using a CCD camera with Noise level $\sigma = 1$.

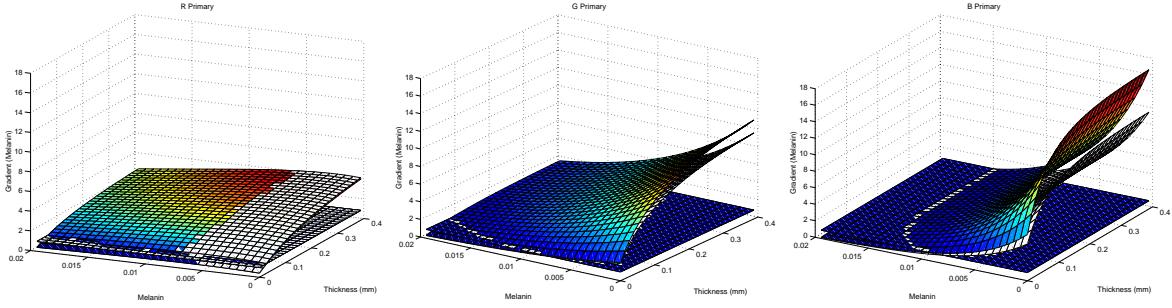


Figure 4: Absolute value of the gradient of R, G, and B primaries with respect to melanin concentration. The measurement is performed for two extreme levels of blood concentrations (100 and 700).

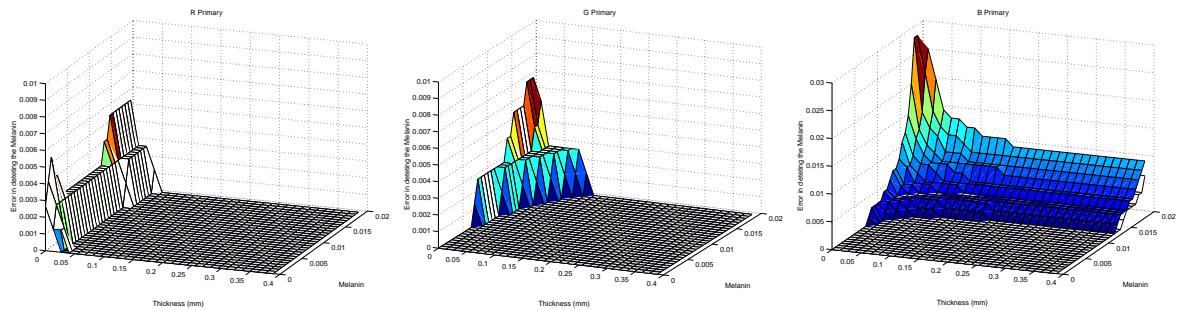


Figure 5: The error in measuring melanin based on every single primary when a CCD camera with uniform noise level, $\sigma = 1$, is applied.

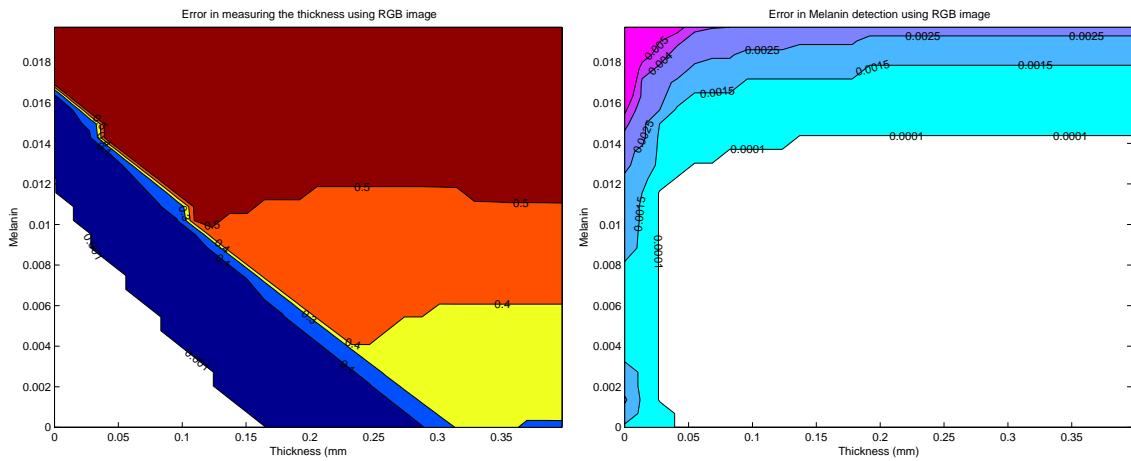


Figure 6: The error in measuring the papillary dermal thickness and melanin concentration in normal skin when a CCD camera with uniform noise level, $\sigma = 1$, is applied.

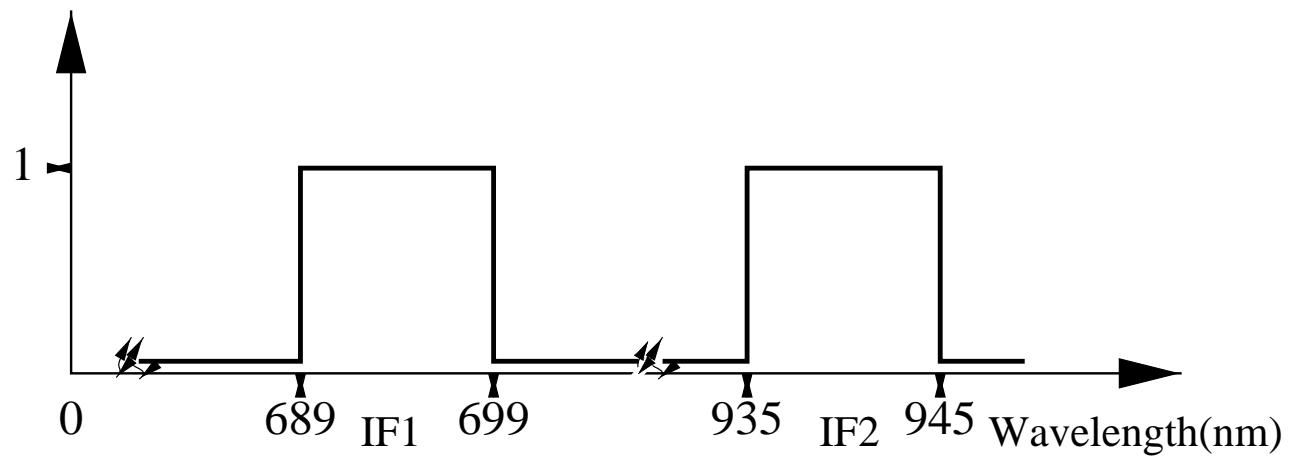


Figure 7: The bandwidth (wavelength range) of the two infrared primaries “IF1” and “IF2”.

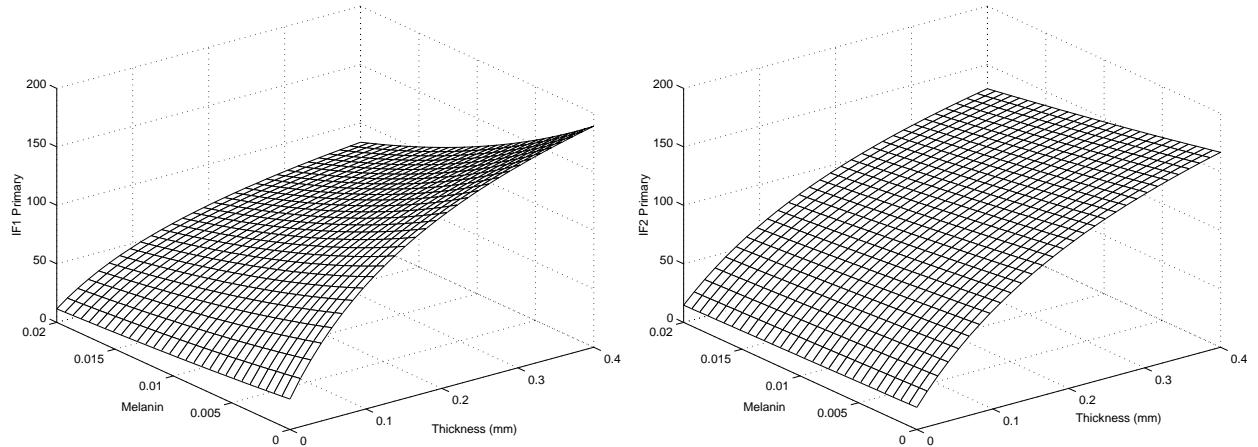


Figure 8: Infrared primaries for a normal skin with different levels of epidermal melanin and papillary dermal thickness.

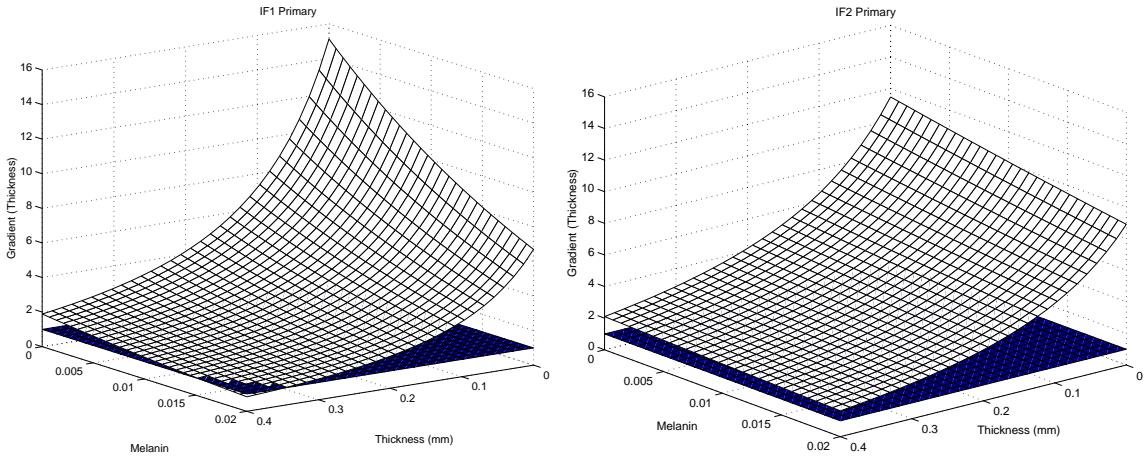


Figure 9: Absolute value of the gradient of infrared primaries with respect to papillary dermal thickness.

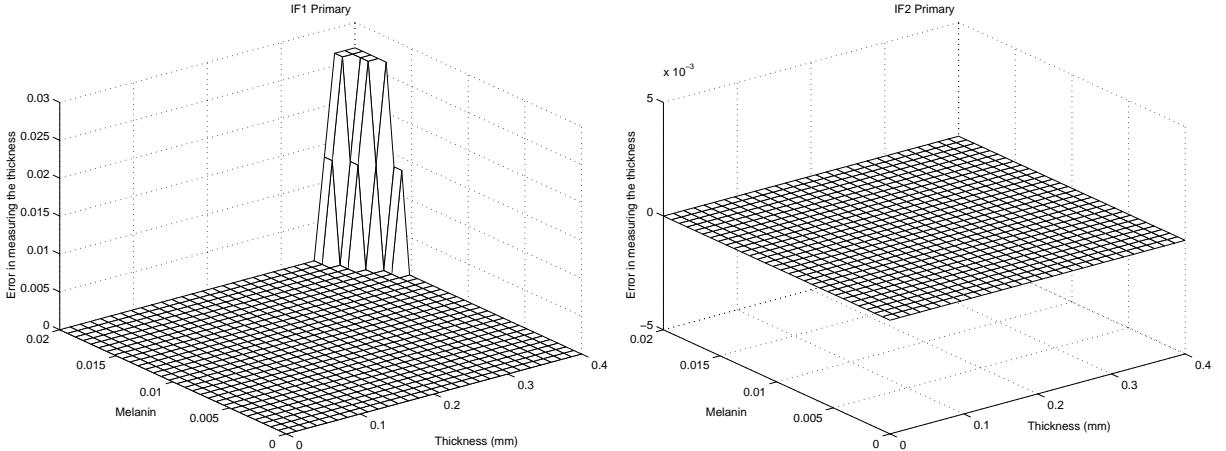


Figure 10: The error in measuring the thickness based on the two infrared primaries using a CCD camera with Noise level $\sigma = 1$.

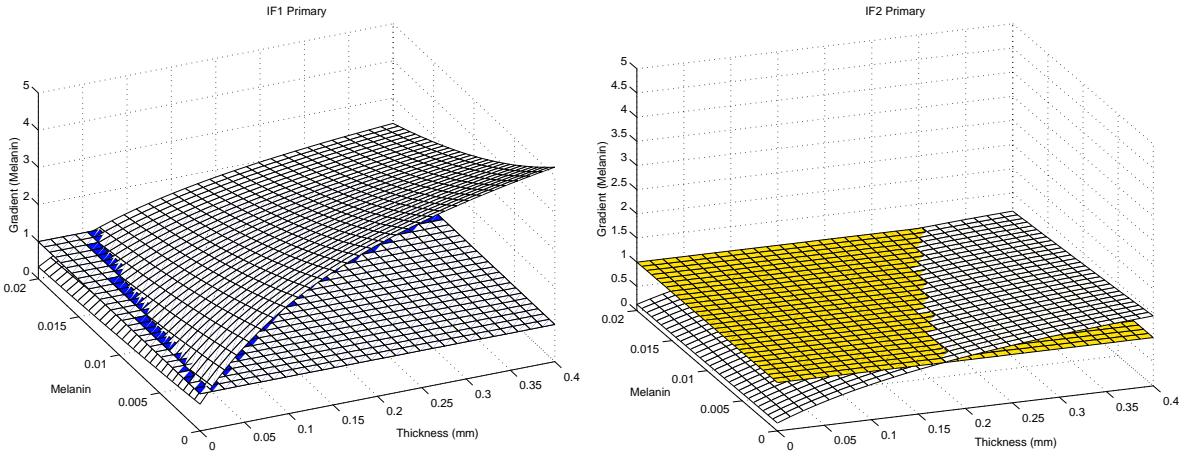


Figure 11: Absolute value of the gradient of infrared primaries with respect to melanin concentration.

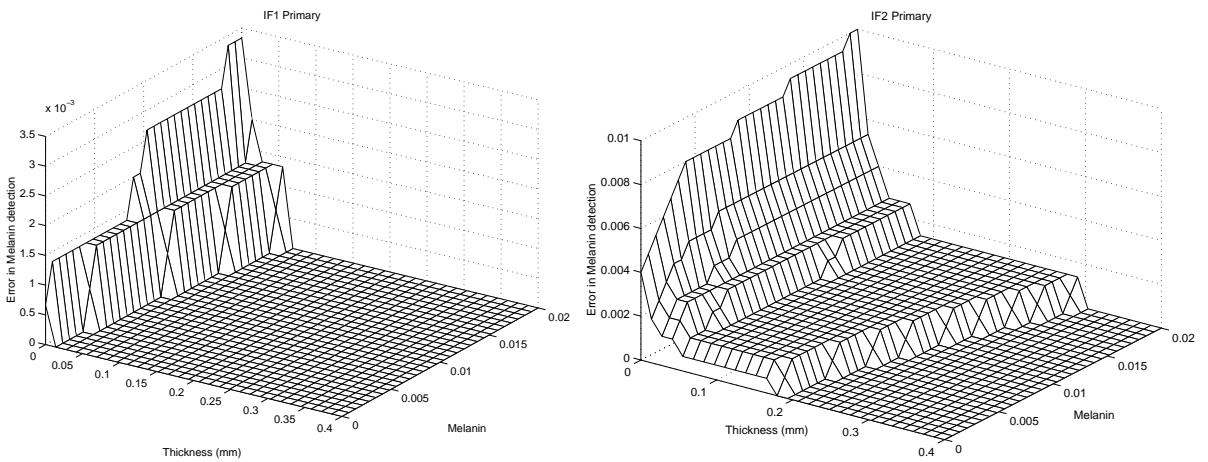


Figure 12: The error in measuring melanin based on the infrared primaries when a CCD camera with uniform noise level, $\sigma = 1$, is applied.