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High sensitivity optical measurement of skin gloss

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Abstract: We demonstrate a low-cost optical method for measuring the gloss properties with improved sensitivity in the low gloss regime, relevant for skin gloss properties. The gloss estimation method is based on, on the one hand, the slope of the intensity gradient in the transition regime between specular and diffuse reflection and on the other on the sum over the intensities of pixels above threshold, derived from a camera image obtained using unpolarized white light illumination. We demonstrate the improved sensitivity of the two proposed methods using Monte Carlo simulations and experiments performed on ISO gloss calibration standards with an optical prototype. The performance and linearity of the method was compared with different professional gloss measurement devices based on the ratio of specular to diffuse intensity. We demonstrate the feasibility for in-vivo skin gloss measurements by quantifying the temporal evolution of skin gloss after application of standard paraffin cream bases on skin. The presented method opens new possibilities in the fields of cosmetology and dermatopharmacology for measuring the skin gloss and resorption kinetics and the pharmacodynamics of various external agents.

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References and links

1. J. Ripoll, D. Yessayan, G. Zacharakis, and V. Ntziachristos, "Experimental determination of photon propagation in highly absorbing and scattering media," J. Opt. Soc. Am. A **22**(3), 546–551 (2005).
2. W. Ji, M. R. Pointer, R. M. Luo, and J. Dakin, "Gloss as an aspect of the measurement of Appearance," J. Opt. Soc. Am. A **23**(1), 22–33 (2006).
3. A. Ponticorvo, D. M. Burmeister, B. Yang, B. Choi, R. J. Christy, and A. J. Durkin, "Quantitative assessment of graded burn wounds in a porcine model using spatial frequency domain imaging (SFDI) and laser speckle imaging (LSI)," Biomed. Opt. Express **5**(10), 3467–3481 (2014).
4. N. Samson, B. Fink, and P. J. Matts, "Visible skin condition and perception of human facial appearance," Int. J. Cosmet. Sci. **32**(3), 167–184 (2010).
5. A. Matsubara, Z. Liang, Y. Sato, and K. Uchikawa, "Analysis of human perception of facial skin radiance by means of image histogram parameters of surface and subsurface reflections from the skin," Skin Res. Technol. **18**(3), 265–271 (2012).
6. J. C. Huff, W. L. Weston, and M. G. Tonnesen, "Erythema multiforme: A critical review of characteristics, diagnostic criteria, and causes," J. Am. Acad. Dermatol. **8**(6), 763–775 (1983).
7. W. G. van Lankveld, M. C. Vonk, H. Teunissen, and F. H. van den Hoogen, "Appearance self-esteem in systemic sclerosis--subjective experience of skin deformity and its relationship with physician-assessed skin involvement, disease status and psychological variables," Rheumatology (Oxford) **46**(5), 872–876 (2007).
8. L. Li, C. So-ling Ng, "Rendering human skin using a multi-layer reflection model," Int. J. Math. Comput. Simul. **1**(3), 44–53 (2009).
9. H. Ding, J. Q. Lu, K. M. Jacobs, and X. H. Hu, "Determination of refractive indices of porcine skin tissues and Intralipid at eight wavelengths between 325 and 1557 nm," J. Opt. Soc. Am. A **22**(6), 1151–1157 (2005).
10. D. T. Downing, "Lipid and protein structures in the permeability barrier of mammalian epidermis," J. Lipid Res. **33**(3), 301–313 (1992).
11. A. Jarrett, *The Physiology and Pathophysiology of the Skin* (Academic Press, 1986).

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12. P. M. Elias and G. K. Menon, "Structural and lipid biochemical correlates of the epidermal permeability barrier," Adv. Lipid Res. **24**, 1–26 (1991).
13. P. E. Pochi, J. S. Strauss, and D. T. Downing, "Skin Surface Lipid Composition, Acne, Pubertal Development, and Urinary Excretion of Testosterone and 17-Ketosteroids in Children," J. Invest. Dermatol. **69**(5), 485–489 (1977).
14. B. Y. Kim, J. W. Choi, K. C. Park, and S. W. Youn, "Sebum, acne, skin elasticity, and gender difference - which is the major influencing factor for facial pores?" Skin Res. Technol. **19**(1), e45–e53 (2013).
15. W. Abramovits and A. Gonzalez-Serva, "Sebum, Cosmetics, And Skin Care," Dermatol. Clin. **18**(4), 617–620 (2000).
16. W. J. Cunliffe and S. Shuster, "The rate of sebum excretion in man," Br. J. Dermatol. **81**(9), 697–704 (1969).
17. R. Silvennoinen, K. Peiponen, and K. Myller, *Specular Gloss* (Elsevier, 2008).
18. A. Pfund, "The Measurement of Gloss," J. Opt. Soc. Am. A **20**(1), 23–25 (1930).
19. A. Ezerskaia, S. F. Pereira, H. P. Urbach, R. Verhagen, and B. Varghese, "Quantitative and simultaneous non-invasive measurement of skin hydration and sebum levels," Biomed. Opt. Express **7**(6), 2311–2320 (2016).
20. R. Hunter and R. Harold, *Measurement Appearance,* 3rd ed. (John Wiley & Sons, 1987).
21. M. Matsuta and T. Kubota, "Gloss Measurement on Painted Surfaces," Jpn. J. Appl. Phys. **20**(6), 1145–1152 (1981).
22. G. Kigle-Boeckler, "Measurement of gloss and reflection properties of surfaces," Mat. Finish **93**(5), 28–31 (1995).
23. A. Lentner and V. Wienert, "A new method for assessing the gloss of human skin," Skin Pharmacol. **9**(3), 184–189 (2009).

1. Introduction

Quantitative assessment of the appearance of human skin resulting from complex optical interactions involving surface specular and subsurface diffuse reflections has been a subject of great interest in the fields of dermatology, cosmetology, and computer graphics [1–5]. In dermatology, the assessment of the appearance of the diseased area by the dermatologist is the first and most important step in the diagnosis of dermatological disorders [6]. In cosmetology, the skin radiance associated with subsurface diffuse reflections is a desired skin-beauty attribute whereas skin gloss associated with specular surface reflections is unfavorable [7]. The appearance of skin is significantly influenced by the presence of a thin emulsified film on the skin surface. Sebum containing lipids from sebaceous glands and epidermal keratinocytes is mixed with sweat and other lipids from cosmetics and environment to form this emulsified film of refractive index higher than that of the epidermis [8-9]. This thin layer of skin surface lipids provides barrier protection, regulation of transepidermal water loss and maintenance of the skin biofilm [10–12]. Even though multiple physiological functions of sebum are proposed, sebum is associated with large pore size and the formation of comedonal and inflammatory acne lesions [13]. Sebum causes the skin to look glossier due to higher Fresnel reflection and smooth air-sebum interface. Glossy and oily skin is considered to be unaesthetic and unpleasant and often associated with various dermatological disorders such as seborrhea, acne and hormonal imbalance. In sebum deficit conditions, the skin is vulnerable to infections and it feels itchy, dry, and looks lusterless, erythematous, and scaly. Optimal balance between sebum production and requirements imparts a non-glossy and healthy feel to the skin and is dermatologically and cosmetically desirable [13–16]. As a result strategies are being developed to balance the needs of the skin to its optimal lipid requirements by controlling the sebum secretion rate and to monitor the skin condition using non-invasive optical devices and methods.

Skin gloss measurements resulting from specular reflections depend on the physical properties of the skin, such as refractive index, texture and device characteristics, such as device geometry, angle of incidence and polarization of the incident radiation [17-18]. Many products are currently entering the marketplace to reduce sebum production and overall facial gloss reduction. The refractive index of the skin generally decreases with increased hydration of the skin and thus the skin moisture condition also contribute to the overall gloss appearance of the skin. Right balance between hydration (moisture) and sebum (skin surface lipids) is an indication of healthy skin and plays a central role in protecting and preserving skin health. Many professional and home-use devices are currently available for measuring

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skin sebum and hydration levels. Recently we reported for the first time a non-invasive short wave infrared spectroscopic technique for simultaneous measurement of oiliness and hydration levels of the skin utilizing the differential detection with three wavelengths 1720, 1750, and 1770 nm, corresponding to the lipid vibrational bands that lay "in between" the prominent water absorption bands [19].

The gloss measurement is an established and standardized procedure in paint and surface coating industry [20–22]. Typical industrial gloss meters illuminate the sample surface with a parallel beam of light and measures the specular reflection over a small range of reflection angle. The ratio of reflected to incident light for the test sample compared to the ratio for the amount of reflected light from a highly polished reference black glass standard with a defined refractive index, is recorded as Gloss Units (GU). The gloss measurement scale from 0 (perfectly matte surface) to 100 GU (black glass standard) is suitable for most non-metallic coatings and paints as they generally fall within this measurement range. However this gloss scale is not suitable for highly reflective materials where gloss values above 2000 GU can be obtained and in these applications percentage of reflection of incident light rather than Gloss Units are commonly used.

The industrial gloss measurement method describe above for uniform sample material properties cannot be directly applied for skin which varies in texture and color and also because of the diffuse scattered light resulting from multiple scattering. Furthermore, unlike material surface gloss in industry, skin gloss is very low and only changes within a very narrow range of the gloss scale and therefore high resolution is required in the low gloss regime. Until now only very limited non-contact devices and methods have been reported for the quantitative measurement of skin gloss and the visual grading method remains the main tool for evaluating gloss attributes. The presently used gloss meters used for skin gloss measurements (C&K Skin gloss meter and SAMBA) calculate gloss value from specular and diffuse intensities. C&K Skin gloss meter use two measurement channels to measure the direct and diffuse reflected light and diffuse scattering correction is applied to eliminate the portion of diffuse reflected light. SAMBA gloss measurement device consists of a high resolution digital camera equipped with a liquid–crystal polarizer, the polarization angle of which can be electronically flipped from the direction parallel (*P*) to the plane of polarization of the polarizing filters on the illumination units to crossed (*C*) orientation. SAMBA device utilizes polarization difference imaging and measures polarization state on each pixel in the entire region of interest and then calculates the average value of gloss based on the difference between specular and diffuse reflected components (*P*-*C*). Both devices use device dependent gloss units. The sensitivity of the method based on the ratio of specular to diffuse component in the low gloss regime relevant for skin gloss characteristics is lower than in the high gloss regime.

In this article, we report on two highly sensitive optical methods for quantitative assessment of the skin gloss in the low gloss regime relevant for many applications in cosmetology and dermatopharmacology. The two methods are based on the angle or slope of the intensity gradient in the transition regime between specular and diffuse reflection of the intensity profile along the optical axis in the specular to diffuse transition region and on the number of pixels above a threshold weighted with its intensity. We have used Monte Carlo ray tracing simulations using the LightTools software to calculate the gloss for a full range of samples from 100% specular (mirror) to 100% diffuse (Diffuse standard). We have developed an optical prototype and experiments were performed on ISO calibration standards and the results are compared with an industrial gloss meter (Gardner Micro-Tri-Gloss). In-vivo skin gloss measurements were performed for different gloss conditions and the temporal evolution of skin gloss after the application of different standards cream bases were compared with professional skin gloss measurement devices (SAMBA, C&K Skin gloss meter).

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2. Materials and methods

2.1. Experimental set-up

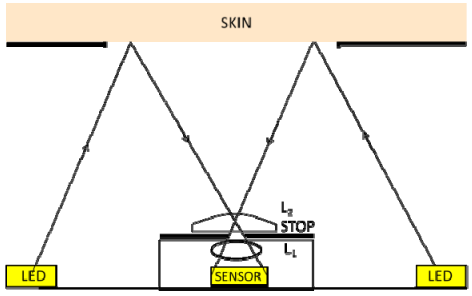

Fig. 1. Schematic of the system model used for the Monte Carlo simulation and the optical prototype.

The imaging optics is based on a low-cost raspberry pi camera module using unpolarized white light illumination (Fig. 1). The skin is sequentially illuminated using four unpolarized white light sources (Luxeon Z white, Lumileds LXZ1-4070) at an angle of incidence with the normal of approximately 22°. A Pi camera imaging sensor of a fixed focus color camera with 2592 × 1944 pixels were used to reduce the processing overhead. To achieve a field of view of about 10 × 7.5 mm and a focus at 10 mm, we placed a f = 10 mm lens on the top of this unit. The stop size of the camera is 1.16 mm and to achieve a larger depth of focus we placed a stop of diameter 0.6 mm between the camera module lens and the f10 lens. The depth of focus and resolving power of the final prototype were 611 µm and 10 µm respectively.

2.2. Monte Carlo simulations

Monte Carlo ray tracing simulations were performed using LightTools software package. The Monte Carlo simulations calculate the photometric and radiometric quantities to perform a complete illumination and detection analysis. The optical configuration of the system used in simulation was based on the optical configuration of the prototype described in Section 2.1. A black box was used around the sensor to prevent signal contribution from the walls that directly hit the sensor without having interacted with the skin. The skin sample is modelled using a surface having a 17% reflectivity. We investigated the full range from 100% specular (mirror) to 100% diffuse (Diffuse standard) by using a phenomenological model for the skin such that all reflection takes place at the air and skin interface. We have used samples with uniform properties in the simulations even though skin properties can vary in texture and color. In the case of samples with uniform properties, illumination from different positions using multiple emitters is expected to give same results. We have modelled the LUXEON LXZ1 4070 LED (color temperature of 4000 K and CRI of 70) as a Lambertain surface emitter and having a package that has 90% diffuse reflectivity. The LED surface is of 70% diffuse reflectivity and zero transmission. The printed circuit board is modelled as having a 60% diffuse reflectivity and zero transition. The walls of the housing and the STOP surface have been modelled as black but not a perfectly black but having 5% diffuse reflectivity and zero transmission. The lenses are modelled having refractive indices corresponding to the N-LASF9 and the N-BK7 glass in the visible region for the larger and smaller lens, respectively.

2.3. Image processing algorithms for gloss estimation

We used two approaches for estimating gloss value from the image. The methods are based on the angle (slope) of the intensity profile as a function of distance in the transition region from specular spot to diffuse background and the number of pixels above a threshold weighted with the corresponding pixel intensity.

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To calculate the angle (slope), the following steps are followed. The RGB image is converted to a gray scale image in MatLab by forming a weighted sum of the R, G, and B components. To convert color image to gray the following standard Matlab formula is used: gray = 0.2989 *red + 0.5870 * green + 0.1140 * blue. First a window is selected in the region of the specular reflection, and the average intensity of in this region of interest is calculated as a function of distance in the specular to diffuse transition regime and the last window is selected to be in the area of diffuse reflection (Fig. 2(a)). The desired number of windows is built along the line connecting the centers of the first and the last windows (Fig. 2(b)). The average intensity is calculated for every window. The averaged intensity values are plotted as function of the spatial coordinate of the window. Close to the specular reflection region linear regression is applied to estimate the slope of the curve (Fig. 2(c)) and the angle between resulting tangent to the curve and the horizontal axis is used as indicator of surface gloss. This intensity profile typically has 2 slopes (left and right) and a plateau. We chose the right slope for the estimation of the angle with the x-axis and that slope is estimated by linear regression. Higher gloss of the surface contributes to a higher specular component and a resulting curve of average intensities that has a larger slope, leading to a higher value for the angle.

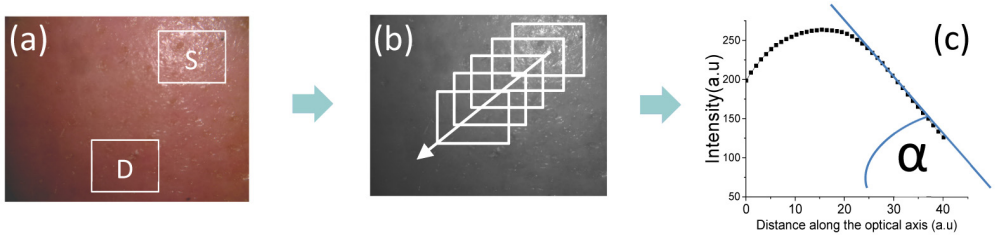

Fig. 2. Schematic representation of gloss measurement method based on the angle (slope) of the intensity profile in the transition region from specular spot (S) to diffuse background (D).

For the method based on the number of pixels above a threshold weighted by the intensities, the RGB image (Fig. 3(a)) is first converted to a gray scale image in MatLab by forming a weighted sum of the R, G, and B components (Fig. 3(b)). We sum the intensities of all pixels whose intensity is above the threshold (i.e. the pixels shown in Fig. 3(c)) and this is translated into Gloss Units based on a reference scale used by industrial gloss meter, Gardner.

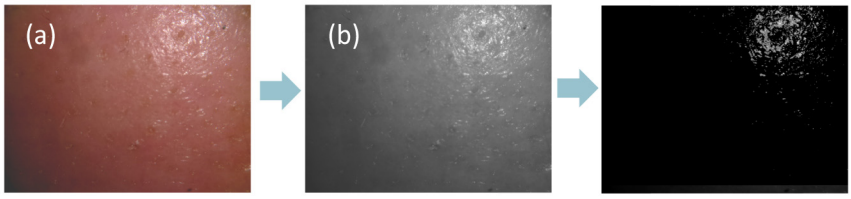

Fig. 3. Schematic representation of gloss measurement method based on the number of pixels above a threshold weighted with intensity.

The gloss value calculated using the method presented here are compared with the method based on the ratio of the specular to diffuse reflection, used in traditional gloss measurement devices such as Gardner Gloss meter (Micro-Tri-Gloss) and Skin gloss meter (Courage & Khazaka). Gloss measured in terms of slope and sum over the intensities of pixels measured on calibration samples are expressed in Gloss Units based on the Industrial gloss meter, Gardner measured at an angle of incidence of 600. No standardized measurement units are currently available for measuring gloss on skin which exhibit non-uniform properties and therefore different skin gloss meters use different device dependent gloss scales. Gloss measurements on skin performed with two professional skin gloss measurement devices and

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the prototype are normalized to the baseline value obtained before the application of the cream.

2.4. Calibration using reference standards

In traditional gloss measurement devices, the angle of incidence (AOI) and the optical geometry used for gloss measurements depend on the gloss property of the sample. Typically, the sample is first measured in a 60°geometry. If the gloss value is higher than 70 G.U. (high gloss), then it is re-measured at 20°, and, if the gloss value is less than 10 G.U. (low gloss), it is re-measured at 85°. The reason for this procedure is that the high accuracy is obtained by using 85° for low-gloss samples, 60° for semi-gloss samples, and 20° for high-gloss samples.

We used three highly polished reference black glass standards (Novo Gloss) with a defined refractive index having a known ISO reference gloss units of 10.2, 21.9 and 52.3 GU at an angle of illumination of 60° as 'calibration tiles' or 'calibration standards' in the high gloss regime. The gloss values of these calibration tiles were first measured using a professional industrial gloss meter (Gardner) at an angle of illumination of 60 ° and was found to be in the range of mid to high gloss value range (between 10 and 70 G.U). These calibration standards have assigned gloss unit values for the angle of 60 ° and are traceable to BIN standard for Material Research. We have used different industrial gloss papers to measure the performance and linearity of our method for low gloss value samples. The gloss values of these paper samples measured with Gardner (AOI = 60°) were less than 10 G.U, corresponding to the low gloss regime. The measurement results obtained with the camera prototype on calibration tiles and gloss papers are expressed in Gloss Units GU measured with the industrial Gloss meter, Gardner for AOI = 60°.

2.5. In-vivo skin gloss measurements

In-vivo measurements were performed for different gloss conditions of the skin. We quantified the evolution of skin gloss on the forehead after the application of liquid paraffin which cause various levels of gloss. Reference gloss measurements were performed using a professional whole-face image gloss measurement device from Bossa Nova Technologies, SAMBA and skin gloss meter from Courage & Khazaka. The temporal evolution of skin gloss measured with different devices are normalized to the baseline value measured before the application of the cream.

3. Results

3.1. Monte Carlo simulations

Figure.4 shows the examples of simulated power density distributions on the sensor for three different gloss values. As the gloss value of the sample is changed from a 100% specular (Fig. 4(a)) to 100% diffuse (Fig. 4(c)), the magnitude of the specularly reflected light drops whereas the diffuse background signal increases. The background signal obtained on the sensor for diffuse samples corresponds to the diffuse scattered photos resulting from multiple scattering. Figure 5 shows the gloss value estimated using the methods based on slope, weighted sum over pixels above threshold and specular to diffuse ratio.

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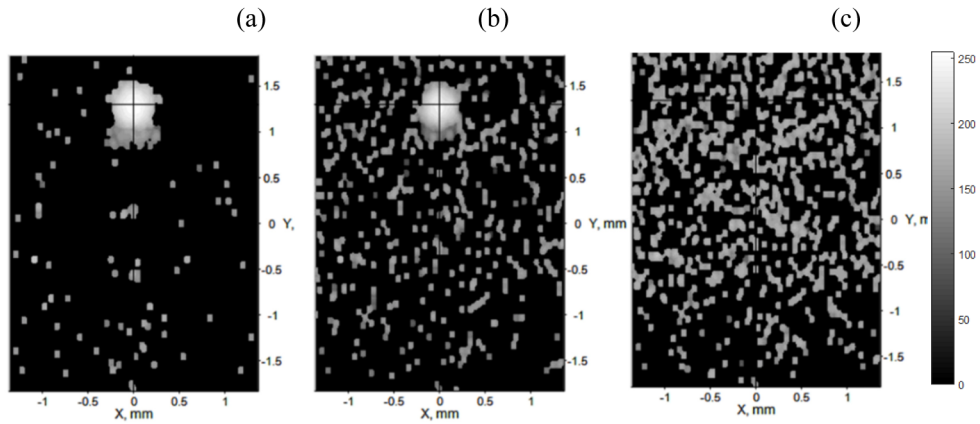

Fig. 4. The power distribution on the sensor obtained for different gloss values using Monte Carlo simulations: (a) 100% Glossy, (b) 50% Glossy/ 50% Diffuse, (c) 100% Diffuse. The grey values are the logarithm of the power density.

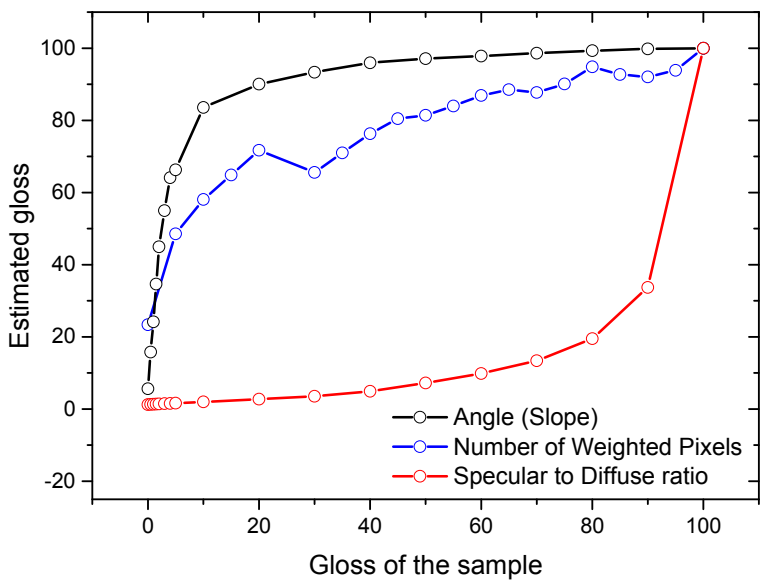

Fig. 5. The gloss value estimated using Monte Carlo ray tracing for samples with gloss values ranging from 0% (diffuse standard) to 100% (mirror).

The results of comparing both methods to the standard ratio between specular and diffuse reflection show that the sensitivity of our two methods is high for samples in the low gloss regime and in particular for samples with glossiness in the range from 0 to 20% (Fig. 5). Therefore we expect that our methods are very suitable for measuring gloss values of skin, since, unlike material surfaces in industry, these are low and change only within a very small range. On the other hand, the sensitivity of the traditional specular to diffuse intensity ratio method is high for high gloss samples.

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3.2. Measurements on ISO gloss Calibration standards

Figure 6 shows the comparison of the gloss value measured with our two new methods on ISO calibration tiles having high gloss, with the gloss values obtained with the Gardner professional gloss meter using an angle of illumination of 60°. The same comparison done for low gloss samples is shown in Fig.7. We observe that the measurement sensitivity of the different methods depends on the gloss value of the samples. For lower gloss values, the measurement sensitivity of the slope method and the method based on the number of weighted pixels are higher than that of ratio of specular and diffuse reflection. In the case of samples with medium gloss values, the method based on the number of weighted pixels and the ratio of specular to diffuse reflection are more sensitive than the angle method. These observations are consistent with the results of Monte Carlo simulations described in Section 3.1.

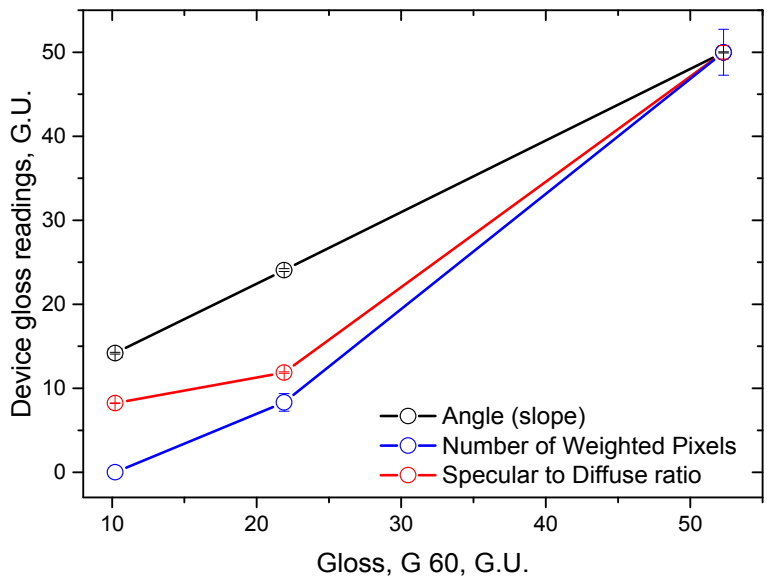

Fig. 6. The gloss values estimated on ISO Gloss calibration tiles in the high gloss regime measured with the camera prototype and algorithms and comparison to professional Gloss meter measurements using angle of illumination of 60°.

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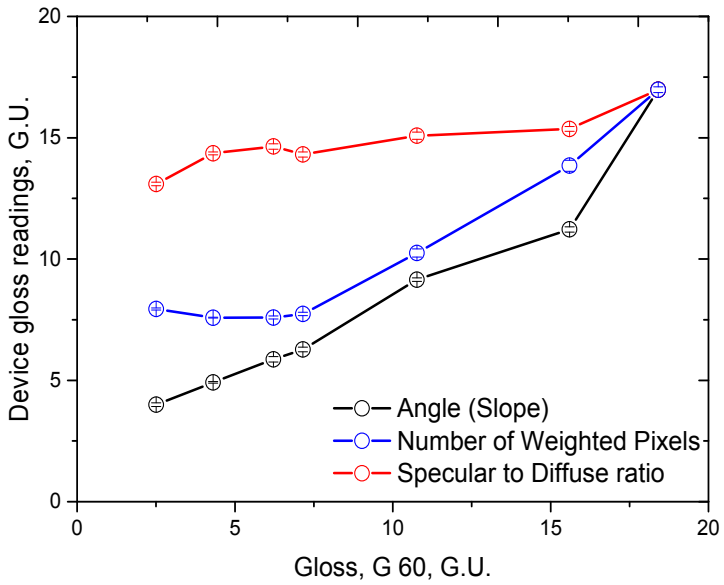

Fig. 7. The gloss values estimated on gloss papers in the low gloss regime measured with the camera prototype and algorithms and comparison to professional Gloss meter measurements using angle of illumination of 60°.

3.3. In-vivo skin gloss measurements

Figure 8 shows the temporal evolution of skin gloss value after the application of liquid paraffin to the skin. The results obtained using our optical prototype are compared with professional gloss measurements devices such as Courage & Khazaka and SAMBA. The temporal evolution of the gloss value of all skin measurement methods give increased gloss value within the first minute after the application of paraffin. Paraffin is applied in a liquid form, which spreads on the skin surface beyond the application area. Such a behavior results in a decrease in the gloss value with time in the area of interest [23].

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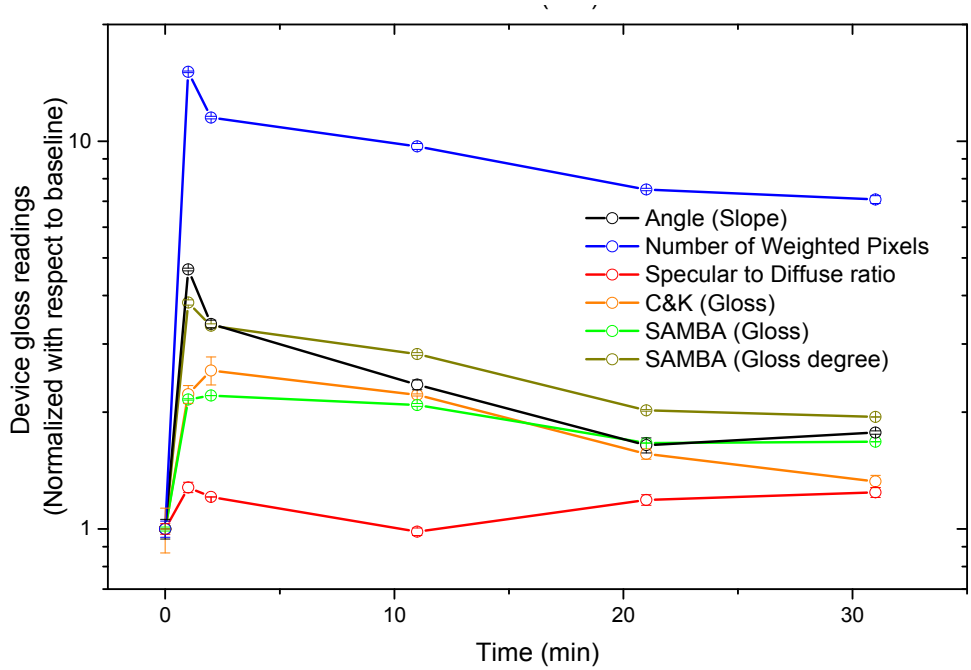

Fig. 8. The temporal evolution of skin gloss values after application of liquid paraffin. Experimental results obtained with the camera prototype are compared with professional devices for skin gloss measurements.

4. Discussion

Here we present two new optical methods for measuring the gloss characteristics of skin with high sensitivity in the low gloss regime, unlike the high gloss material samples used in industry. The sensitivity of current gloss meters used in industry is rather limited in particular for skin gloss measurements where gloss is low. The low-cost optical method presented permits fast, contactless and randomly repeatable quantitative measurement of skin gloss, which can be used for defining the acceptance criteria for various external agents that can cause greasy and glossy appearance to the skin. This opens new possibilities in the fields of cosmetology and dermatopharmacology for measuring skin gloss and for analyzing the resorption kinetics and the pharmacodynamics of various external agents. Our new method can also test with high sensitivity the acceptance of various cosmetic and pharmaceutical products that are used for influencing the skin gloss conditions.

The sensitivity of the gloss measurement devices strongly depends on the measurement geometry and currently, different angle of illumination are used in industry depending on the gloss levels. 85° AOI is more sensitive to differences in the low gloss regime (gloss below 10 GU) whereas 20° AOI has higher sensitivity for high gloss samples (gloss above 70 GU). The detectable differences in gloss depends on the gloss level of the sample and the consumer relevance of these detectable differences depends on how many units of gloss units would be subjectively perceived as significantly different. For instance 3.0 GU difference measured on a very matt surface with a gloss value below 10 GU would be seen by the human eye but on a higher gloss sample with a gloss value above 70 GU the difference would be very difficult to notice.

Our initial results show that a single camera device with two algorithms, can be used for measuring a broad range of gloss values without any hardware modifications for the angle of illumination. The two algorithms based on slope estimation and the number of weighted

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pixels above threshold show high sensitivity in the low-gloss regime whereas the traditional method based on the ratio of specular to diffuse reflection shows high sensitivity in the high-gloss regime. The algorithm based on the number of weighted pixels gives reasonably good sensitivity for both low and high gloss samples.

The high-gloss regime is characterized by predominant specular reflection. The reflection tends to become nearly an image of the light source for high gloss samples. The intensity profile along the optical path does not change significantly with variation of the gloss value of the surface in high gloss regime. Therefore, the angle (slope) of the intensity profile also does not change significantly. The recorded intensity of the light source reflection yet becomes higher with increase in gloss value of the reflecting surface, while the diffuse component of the reflection decreases. Therefore the method based on the ratio of specular to diffuse reflection is more sensitive for samples with high gloss. However, such high gloss values do not occur for skin.

Our in-vivo experimental results show that our method is able to discriminate between different gloss levels that are physiologically relevant for skin. As expected, methods based on estimation of the angle or slope of the intensity profile and the method based on the sum of weighted pixels show high sensitivity to the temporal evolution of the gloss value of the skin, in particular in the low gloss regime. The method based on the ratio of specular and diffuse reflection is not sensitive enough to detect changes in the skin gloss because the gloss values are too low. However with the Samba professional gloss camera changes in the skin gloss values can be detected. The Courage & Khazaka Glossmeter based on specular reflection estimation with correction on diffuse component, is sufficiently sensitive to skin gloss changes even in the low-gloss regime. The reason may be the geometry of the sensor. Traditionally gloss meters used in the paint industry and for coatings are produced with light source and detector that are spatially separated by several centimeters. The Courage & Khazaka Glossmeter probe has a geometry where the distance between source and detector is few mm, so that the diffuse reflected light can be detected.

The experimental results obtained on calibration standards and gloss papers using the prototype show good agreement with the Gardner professional gloss measurement device. The measurement sensitivity obtained on calibration samples with uniform surface properties may deteriorate when experiments are performed on skin with anticipated non-uniform surface properties and low gloss values. Also, the measurement of skin gloss using our set-up can, like any other optical gloss measurement method, be influenced by for example, skin color, the extend of skin doming depending on the applied pressure and the amount of sebum, sweat etc. on the skin surface. Skin color probably will give only an effect of intensity difference in blue, green or red channels and can be compensated by auto intensity correction in a final system.

When unpolarized light is reflected by a skin surface, the polarization properties of the reflected light depends on the angle of illumination. ISO and ASTM standards for gloss measurements do not describe the conditions for polarization in the illumination and detection path. Previous reports on the polarization effects for gloss measurements showed significant effect of polarization on Fresnel reflectance of the black-glass reference standard. When the angle of illumination is close to polarizing angle or the Brewster angle of about 57°, strong polarization effects may occur in gloss measurements. However, in our current optical geometry using small angle of illumination of about 23°, the magnitude of the polarization error is expected to be smaller than that for large angles of incidence.

The micro-gloss measurements realized with our camera prototype in a maximum field of view of few cm^2 may not be the same as the human visual perception of skin gloss, where the whole face is viewed. Nevertheless, our gloss measurements show good correlation with the corresponding small area measurements derived from the full face gloss image measured with SAMBA. Due to the relatively large illumination and viewing beam field angle of a camera prototype resulting from the divergence of LED source, we expect that our method may

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correlate better to the gloss scale derived from visual perception than the point measurements using collimated narrow beam small spot gloss measurements. The number of pixels weighted with intensity approach could be used in "gloss mapping mode" to instantly represent the spatial distribution of the gloss of a complex, pixel by pixel whereas methods based on slope and on the ration of specular to diffuse reflection only give an average gloss value.

5. Conclusions

We report a low-cost optical method with improved sensitivity for the quantitative assessment of the gloss of human skin in the low gloss regime relevant for skin gloss conditions. We have used Monte Carlo simulations, experiments on gloss calibration standards and in-vivo skin gloss experiments to demonstrate the improved sensitivity of the proposed method in the low gloss regime compared to traditional skin gloss measurement methods. Experimental results obtained with the optical prototype and the algorithms that we have developed, were compared with professional industrial gloss meter and professional skin gloss measurement devices. The proposed method opens new possibilities for fast, contact less quantitative assessment of the skin gloss in the low gloss regime in the fields of cosmetology and dermatopharmacology in measuring the resorption kinetics and the pharmacodynamics of various external agents.

Disclosures

The authors declare that there are no conflicts of interest related to this article.