Optical Review (2018) 25:694–700
https://doi.org/10.1007/s10043-018-0462-z

REGULAR PAPER

Scanning of skin gloss by a diffractive optical element-based handheld glossmeter

Benjamin O. Asamoah[1] · **Kai-Erik Peiponen**[1]

Received: 30 June 2018 / Accepted: 1 October 2018 / Published online: 10 October 2018

Abstract

Skin specular gloss (referred to as "gloss'') determination is important in dermatology and cosmetic industry as it gives an indication of the skin health and beauty. Its accurate determination is, therefore, necessary. Commercially available glossmeters typically employ large incidence angle geometry, large illumination area, and fixed point measurements making them impractical regarding measurement of curved and complex non-planar objects or surfaces as well as low gloss regime such as the skin. In this study, we have demonstrated the novel application of a diffractive optical element-based handheld glossmeter with scanning capability, overcoming the disadvantages of conventional glossmeters, in the accurate determination of skin gloss and gloss profile for different skin types under different measurement conditions. Different parts of the body (back of the hands, the inner part of the arm and the forehead) of four volunteers with light, dark and intermediate skin types were scanned (also in different directions) to obtain the skin gloss profile and the statistical average skin gloss. Additionally, the skin surface was modified by arm extension and scanned as well. Our preliminary results showed that the statistical average skin gloss reading increased with the increasing lightness of skin. Areas with higher sebaceous glands (forehead) showed higher gloss reading than the other body parts (inner arm and back of the hand). However, the roughness of the skin surface decreased the statistical average skin gloss reading. The handheld scanning skin glossmeter allows for the accurate determination of skin gloss with sensitivity to small variation in the skin surface roughness with high repeatability.

Keywords Skin gloss · Skin gloss profile · Handheld glossmeter · Skin surface roughness

1 Introduction

Low-cost, simple and easy-to-use optical devices in the assessment of skin properties have become important in healthcare and the cosmetic industry. The optical properties of skin are influenced by the color, age, texture [1], the refractive index [2, 3], and the anisotropic nature of the sub-skin layer. Conventional devices for the measurement of skin parameters, e.g., aging involve the use of confocal microscopy [4], among others, which are comprehensive but expensive for the persons who readily need them.

An important parameter in the definition of skin appearance, analogous to the characterisation of material surface quality, is the skin specular gloss, which is referred to as "gloss." The measure of skin gloss, therefore, is important in dermatology and cosmetology as it helps in the evaluation of skin health and beauty, respectively. This parameter is characterized by reflection of polarized light from the skin surface and unpolarized light from subsurface [5]. They, respectively, lead to the specular and diffuse reflection of the incident light. Therefore, in the characterisation of skin gloss, specular or diffuse reflectance or their combinations have been used [6], among other methods. Skin gloss is also known to be significantly influenced by the surface roughness, which can sometimes be enhanced after skin rejuvenation [7, 8]. The skin is patterned with grooves whose depth is known as the sulci cutis (DSC) and the distance between them is the cristae cutis (DCC).

In addition to the factors contributing to skin optical properties, skin gloss is also influenced by external factors such as the light source [9, 10] (wavelength, intensity and

✉ Benjamin O. Asamoah
benjaasa@uef.fi

Kai-Erik Peiponen
kai.peiponen@uef.fi

[1] Department of Physics and Mathematics, University of Eastern Finland, P. O. Box 111, FI-80101 Joensuu, Finland

polarization) and measurement geometry [6] in terms of angle of incidence. It has also been demonstrated that low-level laser source in the visible or near infrared region presents better light–tissue interactions, especially, in the biological medium than LEDs. Optimal wavelengths that have been suggested for skin characterisation and laser therapy are 635 and 650 nm [1, 11, 12].

In this study, we propose the use of a robust diffractive optical element (DOE)-based handheld glossmeter to accurately measure skin gloss of selected individuals with different skin color in the low gloss regime. The gloss value given by the device refers to the skin specular gloss. Details on the theory and sensing capabilities of the DOE, which is a computer-generated hologram, are given in [9]. We considered the influence of different skin types on the scanned gloss profile and their respective statistical gloss average. The gloss profile gives the variation of the local gloss (level) value with distance on skin surface. The gloss level indicates the magnitude of local gloss and depends on both the surface roughness and the local refractive index of the skin. The same skin type was also scanned in different directions. Finally, natural strain was exerted on the skin by means of arm extension at different angles, and the corresponding modified skin surface was scanned. Recently, the DOE-based handheld glossmeter has also been complimentary utilized in the surface quality determination of pharmaceutical tablets for fake drug screening [13]. However, for skin-related study, the utilization of the handheld glossmeter is demonstrated in this paper for the first time. Different forms of the DOE-based glossmeter exist for industrial applications [14]. For example, the DOE-based sensor has been used in the detection of extremely low gloss of 0.0079 G from nano-carbon surfaces [15].

Other commercial devices for skin gloss determination are usually for fixed point measurements. They usually require a large angle of incidence for large area illumination, especially, in the determination of low gloss. Furthermore, according to the international gloss standards, the surface should be flat. The standard requirements of large area illumination and flat surface for commercial glossmeters make it incapable of resolving the gloss variation arising from the microscopic topography of the curved skin surface and deformation due to exerted pressure. The DOE-based handheld glossmeter, however, resolves these challenges by utilizing low angle of incidence with micrometer spot size of beam. It, therefore, measures the gloss from a very small area hence curved skin surface is seen as locally flat obtaining local gloss estimate that depends on the local conditions of the skin, surface roughness and refractive index. Additionally, the low angle of incidence and the smaller spot size help to achieve a more compact device. More importantly, the integration of the device to a computer also allows the scanning of some skin length [14], a feature which is an additional advantage over other devices for skin gloss determination [5, 6] to the best of our knowledge. Examples of such scanned profiles are shown under the results section.

The aim of this study is, therefore, to provide dermatologist with a handheld device to monitor skin diseases such as psoriasis as well as to provide a handheld glossmeter for cosmetologist for the accurate monitoring of face and body lifting procedures, for example, the quantitative evaluation of iontophoresis and hyaluronic acid in skin care. Usually, these observation and treatment require long campaign. We, however, wish to demonstrate the potential of the DOE-based handheld device, novel application, to scan skin specular gloss which depends both on surface roughness and spectral properties (color) of skin.

2 Definition of average gloss

Analogous to the description of surface roughness via contact and non-contact methods, the DOE-based glossmeter seeks to provide information on surface gloss along its direction of scan. Thus, we can describe its statistical parameters from the scanned profile. In one dimension, analogous to the average surface roughness (R_a), the statistical average gloss for continuous data points over scanned distance, L, is defined as follows [16]:

$$G_a = \frac{1}{L}\int_0^L |G(x) - \langle G(x)\rangle| \mathrm{d}x, \tag{1}$$

where $G(x)$, which is defined in Eq. (2), is the local gloss at the coordinate x and $\langle G(x)\rangle$ is the mean gloss in a manner that $G(x)$ has a minimum variance about $\langle G(x)\rangle$. Different other types of statistical gloss parameters are also defined in [16] but here for skin gloss, we exploit only the concept of the average gloss.

3 Experimental

The experiment involved the use of the diffractive optical element-based (DOE) handheld glossmeter (MGM-Device Ltd, Finland) for the determination of skin gloss of some selected volunteers. The handheld glossmeter is wirelessly connected to a computer via an infrared (IR) detector, and there is also a display on the head of the device for gloss reading. These two features, display and computer connection, allow the device to be used in various field measurement conditions. The schematics and an image of the handheld glossmeter device in use are shown in Fig. 1. The DOE-based glossmeter consists of a low power (0.8 mW) semiconductor laser source with 635 nm wavelength. In a

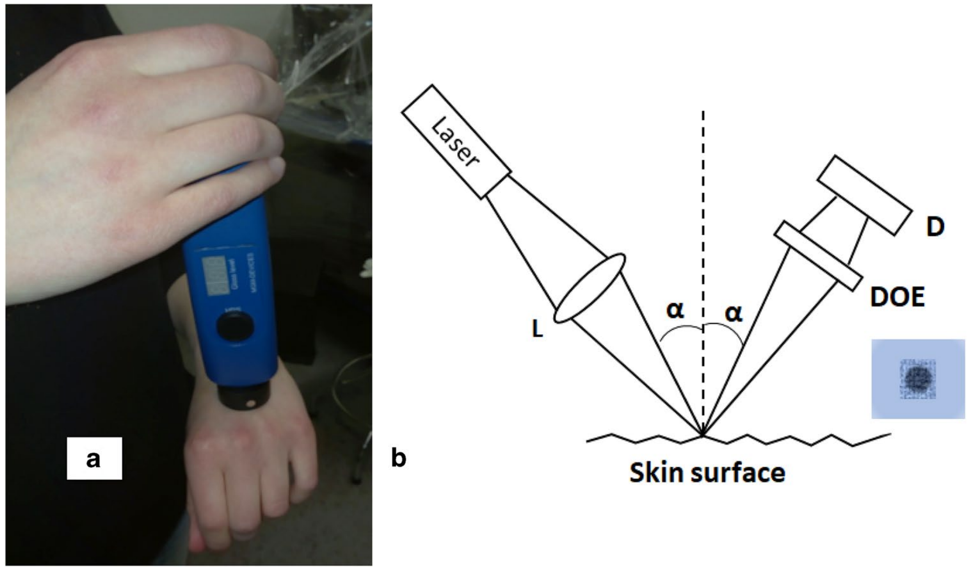

Fig. 1 **a** An image of device in use **b** schematics of the handheld glossmeter, *L* lens, *D* detector, α angle of the incident beam, *DOE* diffractive optical element fabricated with electron-beam lithography, insert: DOE aperture based on Rayleigh–Sommerfeld integral, adapted from [14]

recent thorough study of skin reflectance, it is shown that this wavelength is in favorable spectral range because of negligible absorption and relatively low scattering of such light from skin structures [17] (see earlier studies of skin optics presented in [2, 3]). The beam is focused through a lens with a focal spot of 30 µm in the open aperture (diameter of 2 mm) of the sensor head of the glossmeter. The light passes through the open aperture directly to the skin. The influence of the aperture on the skin is described in the result section. The illumination of the surface is at 6° angle of light incidence. Due to the scattering of the laser beam from skin structure, in the far-field region appears a wavefront that presents laser speckle pattern [1]. The role of the DOE is to act as a wavefront sensor that spatially filters the specular reflection, reducing the noise from the speckle pattern [9], from an object (reconstruction of the computer-generated hologram by a scattered wave) to pass onto a single-cell photodiode, which captures the intensity. This provides gloss reading (with unit G) within the accuracy of ± 0.10 for values below 100 G. The device was calibrated with a highly polished black glass gloss standard (refractive index of 1.543), and also with the Spectralon diffuse reflectance standard. The gloss detected by the handheld device is defined similarly to the standardized gloss definition. The gloss reading of the handheld device is defined as follows:

$$G(x) = \frac{I_{\text{sample}}\,(x)}{I_{\text{reference}}} \times 100, \tag{2}$$

where $I_{\text{sample}}\,(x)$ and $I_{\text{reference}}$ are the detected intensities from the sample and the black glass gloss standard, respectively. This definition is consistent with the conventional gloss definition (with maximum value of 100 GU) but there is no upper limit. It is also important to note that the different definitions of G_{a} and $G(x)$ results in G_{a} having a smaller value compared to $G(x)$ as it is evident in Fig. 3 (LS) and Table 1.

Close to 100% correlation between DOE-based glossmeter and a conventional commercial glossmeter was achieved for gloss data from ceramics, metal, paper and print, and plastic surfaces [16]. In general, paper is made from fibers, fillers and other pigments for controlling the optical and mechanical properties. In addition to this, the finishing processes employed to achieve specific type of paper make the material inhomogeneous at micrometer scale which is comparable to skin in terms of complexity. By this definition of complexity, we believe the DOE-based handheld glossmeter (this glossmeter is practically speaking the same which was developed for online real time measurements of gloss change of prints over paper in printing house environment [18]) can as well be used as a novel tool in the study of skin gloss. Implementing the definition of statistical average gloss in Eq. (1), the use of the device implicitly implies that a single skin gloss profile is treated using statistical models published in [16].

The volunteers were three (3) females and a male. Their skin types are classified as light (LS), intermediate—(IS) and dark skin (DS). The back of the hands (BH), the inner part of the forearm (IA) and the foreheads (FH) of the females were scanned with the device over 6–8 cm to detect the gloss profile. For the male, gloss measurements such as scanning along and across the back of his hands were performed. The directions of the scan are illustrated in Fig. 2. Additionally, his arm was extended at 45°, 90° and 180°, to introduce natural strain on the skin. The skin surfaces under the strain were then scanned, and the average gloss determined. Finally, different levels of pressure—low, medium and very high—were exerted at the back of his hands for fixed point measurements.

The idea of applying the significantly high pressure was to establish the maximum possible variation in the statistical average gloss. Essentially, measurements of different parts of the body for the different skin types help us to obtain relevant information on the device such as the accurate determination of small variation in skin gloss.

The entire process of scanning and transferring of the data to the computer takes 5 s. With the aid of the computer software, we obtain the skin gloss profile and its statistical average gloss from 1000 measurements points. The skin was scanned at as uniform velocity as possible to achieve equidistance of the sample gloss data along the scanned line.

4 Results and discussion

We present the results of the skin gloss by the DOE-based handheld glossmeter for the different skin types in terms of local gloss levels and statistical average gloss for the various measurements.

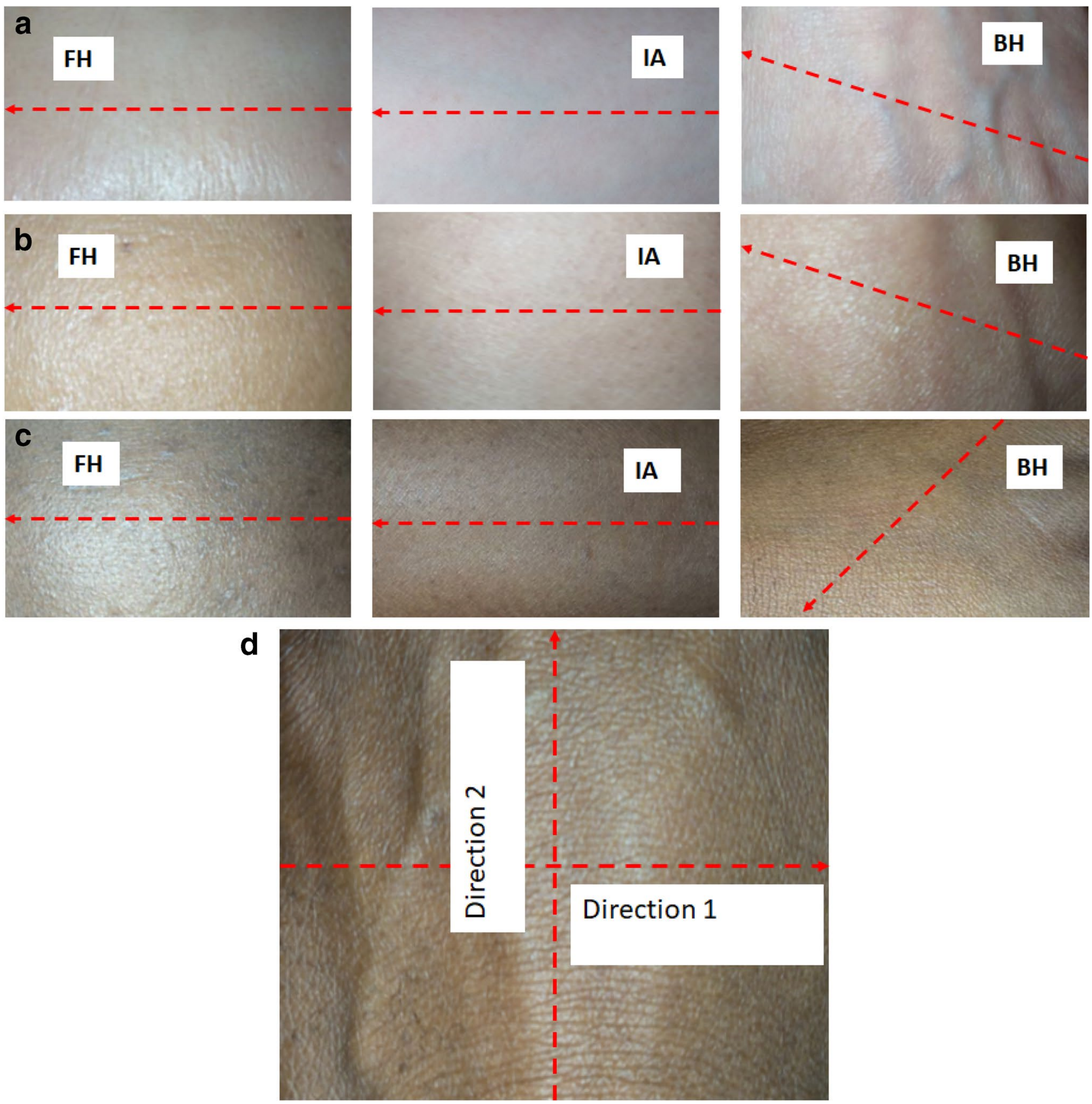

Fig. 2 Images of the measured skin types. Arrow indicates the direction of scan: forehead (FH), inner arm (IA), back of hand (BH). **a** Light skin (LS) **b** intermediate skin (IS) **c** dark skin (DS) and **d** male DS. Directions 1 and 2 are orthogonal to each other

As an example, Fig. 3 shows the surface gloss profile for the LS, at the back of the hand (BH), inner arm (IA) and the forehead (FH). From these profiles, we can distinguish between the different skin types as well as the different scanned parts. The gloss reading depends on skin color, more precisely on the refractive index of the skin. However, the dominant factor for the gloss value is the skin texture.

In the case of the LS, there was a more uniform variation of the gloss level for the different skin parts with the FH showing the highest gloss levels across the measurement points. Similarly, the IS profile also showed uniform gloss level variation for IA and BH with higher gloss level in some areas. DS demonstrated the most random variation in the gloss level for scanned parts. The random nature of the gloss level in DS and FH of IS could be influenced by the random nature of the depth of sulci cutis (DSC) and the distance between the cristae cutis (DCC) as well as strong local variation of the skin surface because of micro-scars or dark spots.

Despite the randomness of the gloss levels at the different scanned skin parts, their statistical average gloss correlated well with the different skin types. Moreover, for the same skin type, we also observed that the average gloss values were different for the different skin parts. Summary of average skin gloss obtained for the various skin types and scanned areas is presented in Table 1.

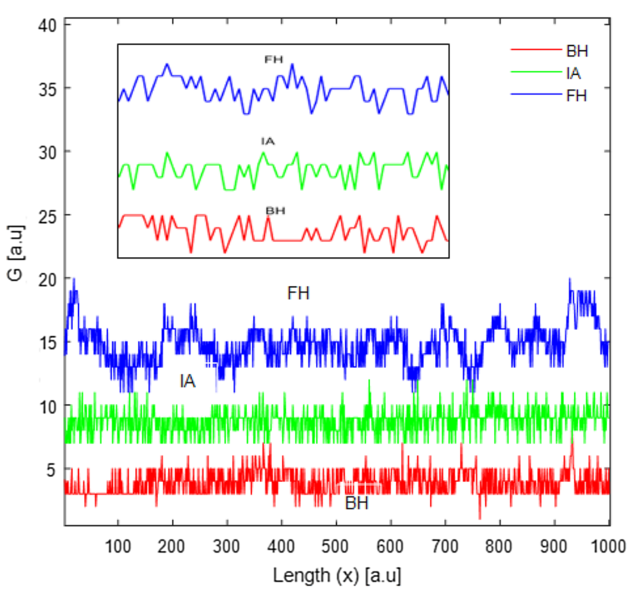

Fig. 3 Gloss profiles for LS female. FH shows higher gloss than IA and BH. The gloss profile curves have almost same the level, but for the sake of clarity, we have separated these curves in the figure. However, the profile for IA is unaltered. Insert: Zoomed gloss profile between 410 and 500

Table 1 Statistical average gloss value with the standard deviations for the different skin types

	BH	IA	FH
LS			
G_a	1.68 ± 0.19	1.89 ± 0.19	2.41 ± 0.30
IS			
G_a	1.85 ± 0.34	1.69 ± 0.20	1.87 ± 0.35
DS			
G_a	1.53 ± 0.20	1.27 ± 0.17	1.71 ± 0.43

G_a average gloss, *LS* light, *IS* intermediate, *DS* dark skin types

At IA and FH scanned parts, the statistical average gloss value, given in Table 1, increased with the lightness of the skin with LS, respectively, having values of 1.89 ± 0.19 and 2.41 ± 0.30. On the contrary, at BH, IS demonstrated higher average gloss value than LS, which was also higher than that of DS. The lower LS gloss value at BH, among other factors, could be largely due to the dryness [1] of the skin evident in Fig. 2a.

Regardless of these variations, however, our results from the DOE-based glossmeter are interestingly consistent with other studies as skin gloss is known to be higher on FH than at the arm [19]. This is explained by the increase in the number and rate of sebaceous glands, responsible for skin oil production, at FH than at other body parts [20, 21]. The presence of sebum produced by the sebaceous glands on the skin surface plays a key role on the skin gloss. It increases the refractive index which, correspondingly, increases the light reflection. However, an excess of it leads to known skin disorders [20, 21]. On the contrary, the presence of skin moisture, correlating with skin health, controlled by hyaluronic acid creates an effective medium with sebum resulting in the lower effective refractive index with negative influence on skin gloss [19, 22]. Thus, the accurate measure of skin gloss will be valuable to the dermatologist and cosmetologist in the treatment of their customers in the determination of skin health and beauty.

Figure 4 shows the surface gloss profile of DS male for the directional measurements and the corresponding statistical average gloss in Table 2. The difference in their statistical average gloss indicates a lesser partial order of DSC “finishing marks” on the skin surface or roughness along direction 1 than direction 2.

Extending the arm at different angles introduces natural strain which modifies skin surface quality [23]. Having the arm at 180° stretch the DCC decreasing the DSC. This makes the skin surface smoother compared to having the arm at 45°. Such skin surface modifications were scanned and the results of the statistical average gloss are presented in Table 2. There was an increase in statistical gloss average with increasing arm extension. Thus, skin gloss decreases with increasing surface roughness.

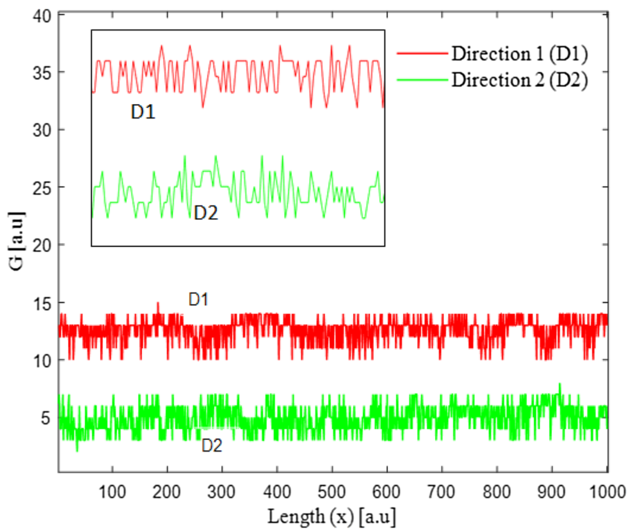

Fig. 4 Gloss profiles of orthogonal measurements of DS male. The statistical average gloss is higher for direction 1 than that of direction 2. The level of gloss profile of Direction 1 was adjusted but that of Direction 2 was unaltered. Insert: zoomed gloss profile between 450 and 560

The effect of pressure exerted on the device on the gloss reading was examined. This was demonstrated by exerting different levels of pressure—low, medium and relatively high—at fixed position and the following statistical average gloss values were, respectively, obtained: 0.76 ± 0.22, 0.85 ± 0.22 and 1.06 ± 0.21. The variation in the above values is as a result of the modification to the skin upon the exertion of pressure. Increasing the pressure causes the area under illumination within the 2 mm open aperture in the sensor head to expand. This results in a convex skin surface, yet flat to the incident light, which decreases the surface roughness. Hence, the increase in the statistical average gloss value with the increase in the exerted pressure. It is worth noting that the device is rather sensitive to such small modification introduced in the illuminated area. It also suffice to say that low-to-medium pressure is likely to be applied which, within the tolerance of the measurements, results in the similar statistical average gloss values.

Table 2 Statistical average gloss value with the standard deviations for directional and with the skin under natural tension measurements

	Direction 1		Direction 2
G_a	1.13 ± 0.21		0.96 ± 0.23
	IA at 45 deg	IA at 90 deg	IA at 180 deg
G_a	1.46 ± 0.11	1.50 ± 0.11	1.52 ± 0.12

IA inner arm, G_a average gloss

The repeatability of the measurements by DOE-based handheld glossmeter was also considered. We, however, note that one cannot precisely scan along the same line in repeated measurements when measuring with a free hand. The same also holds for successive pointwise measurements when trying to measure the exact location with the lifting of the glossmeter after each measurement. Nevertheless, we investigated the repeatability of measured data in the case of fixed measurement point and by exaggerating "less steady hand". In other words, tilting the measurement head over the skin into slightly different angles and measuring gloss for such conditions. In both cases, the gloss variation was in the second decimal as well as the standard deviation, hence showing rather good repeatability of the method at least in such measurement conditions.

5 Conclusion

We have demonstrated the use of a DOE-based handheld glossmeter for skin gloss determination. The features of this robust device such as skin gloss scanning capability; low angle geometry and smaller illumination area make it useful in comparison to other commercial devices in the determination of low gloss, especially for curved surfaces. The display on the device and wireless computer connection allow it to be used in different field measurement conditions. The whole system is portable and can be used in field measurement conditions. Essentially, one improvement would be to design and test a plastic rail of appropriate shape for adaptive skin gloss profile scanning and to control the exerted pressure especially during scanning.

By employing this device, we were able to distinguish between different skin types, namely light skin, dark skin and intermediate skin based on the gloss measurements. The average gloss increased with increasing lightness of the skin types. Additionally, the average gloss was higher in areas with higher sebaceous glands such as the forehead. The natural strain on the skin introduced by arm extension resulted in the slight modification of the skin surface, which was detected by the device. This indicates the sensitivity of the DOE-based handheld glossmeter in detecting small variations in skin gloss. The future study is to generalize the results by increasing the number of volunteers to include different age groups and to study the effect of the use of different face lifting products on their skin under field condition.

Acknowledgements Open access funding provided by University of Eastern Finland (UEF) including Kuopio University Hospital.

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Orun, A.B., Seker, H., Uslan, V., Goodyer, E., Smith, G.: Texture-based characterisation of subskin features by specified laser speckle effects at λ = 650 nm region for more accurate parametric 'skin age' modelling. Int. J. Cosmet. Sci. **39**, 1–7 (2017)
2. Lister, T., Wright, P.A., Chappell, P.H.: Optical properties of human skin. J. Biomed. Opt. **17**, 1–15 (2012)
3. Bashkatov, A.N., Genina, E.A., Tuchin, V.V.: Optical properties of skin, subcutaneous, and muscle tissues: a reiview. J. Innov. Opt. Health Sci. **4**, 9–38 (2011)
4. Longo, C., Casari, A., Beretti, F., Cesarino, A.M., Pellacani, G.: Skin aging: in vivo microscopic assessment of epidermal and dermal changes by means of confocal microscopy. J. Am. Acad. Dermatol. **68**, 73–82 (2013)
5. Wang, J., Pappas, T.N., Mayne, J., Kuesten, C., Majmudar, G.: Determining the influence of image-based cues on human skin gloss perception. In: SPIE Electronic Imaging 2017, San Francisco, 196, 2017
6. Ezerskaia, A., Ras, A., Bloemen, P., Perriera, S.F., Urbach, H.P., Varghese, B.: High sensitivity optical measurement of skin gloss. Biomed. Opt. Exp. **8**, 3981–3991 (2017)
7. Ohtsuki, R., Sakamaki, T., Tominaga, S.: Analysis of skin surface roughness by visual assessment and surface measurement. Opt. Rev. **20**, 94–101 (2013)
8. Zepletalova, A., Pata, V., Janis, R., Kejlova, K., Stoklasek, P.: Objective measurements of skin surface roughness after microdermabrasion treatment. Skin Res. Technol. **23**, 352 (2017)
9. Silvennoinen, R., Peiponen, K., Myller, K.: Specular gloss. Elsevier Science, Amsterdam (2008)
10. Pfund, A.: The Measurement of gloss. J. Opt. Soc. Am. A **20**, 23–25 (1930)
11. Dhiraj, K., Michael, L., Randolph, D.: Optical characterisation of melanin. J. Biomed. Opt. **6**, 404–411 (2001)
12. Hamad, F., Jaafar, M., Hamid, A., Omar, A., Timimi, Z., Houssein, H.: Influences of different low-level laser power at $\lambda = 635$ nm for two types of skin: dark and light. In: Proc. of the 7th IMT-GT UNINET and the 3rd international PSU-UNS conf. on Bioscience: (2010)
13. Bawuah, P., Paakonen, P., Peiponen, K.-E.: Gloss measurement in detection of surface quality of pharmaceutical tablets: a case study of screening genuine and counterfeit antimalaria tablets. J. Eur. Opt. Soc. Rapid Publ. **13**, 1–7 (2017)
14. Kuivalainen, K., Oksman, A., Juuti, M., Myller, K., Peiponen, K.-E.: Advanced glossmeters for industrial applications. Opt. Rev. **17**, 248–251 (2010)
15. Juuti, M., Peiponen, K.-E., Obraztsov, A.N., Silvennoinen, R., Myller, K.: A glossmeter for inspection of surface quality of low gloss nano-carbons surfaces. Opt. Mater. **29**, 1719–1722 (2007)
16. Peiponen, K.-E., Juuti, M.: Statistical parameters for gloss evaluation. Appl. Phys. Lett. **88**, 1–3 (2006)
17. Akaho, R., Hirose, M., Tsumura, N.: Evaluation of the robustness of estimating five components from a skin spectral image. Opt. Rev. **25**, 181–189 (2018)
18. Oksman, A., Kuivalainen, K., Tåg, C.-M., Juuti, M., Mattila, R., Hietala, E., Gane, P.A.C., Peiponen, K.-E.: Diffractive optical element-based glossmeter for the on-line measurement of normal reflectance on a printed porous coated paper. Opt. Eng. **50**(043606-1-), 043606–043609 (2011)
19. Wienert, V.: Skin gloss metry. In: Elsner, P., Maibach, H.I., Merk, H.F. (eds.) Cosmetics. Springer, Berlin (1999)
20. Plewig, G., Kligman, A.M.: Acne and rosacea. 2nd. Springer-Verlag, Berlin (1994)
21. Cunliffe, W.J., Shuster, S.: The rate of sebum excretion in man. Dermatol. **81**, 697–702 (1969)
22. Papakonstantinou, E., Roth, M., Karakiulakis, G.: Hyaluronic acid, a key molecule in skin aging. Dermatondocrinol. **4**, 253 (2012)
23. Maiti, R., Gerhardt, L.-C., Lee, Z.S., Byers, R.A., Woods, D., Sanz-Herrera, J.A., Franklin, S.E., Lewis, R., Matcher, S.J., Carre, M.J.: In vivo measurement of skin surface strain and sub-surface layer deformation induced by natural tissue stretching. J. Mech. Behav. Biomed. Mater. **62**, 556–569 (2016)