e-ISSN:2231-4237

Research & Reviews: Journal of Pharmaceutical Research and Clinical Practice

Capacitive Contact Imaging for Skin Measurements

Perry Xiao*
Engineering for Embedded and Distributed Systems, School of Engineering, London South Bank University, UK

Research Article

Received date: 02/12/ 2015
Accepted date: 02/02/ 2016
Published date: 05/02/2016

***For Correspondence**

Perry Xiao, Course Director, MSc in Engineering for Embedded and Distributed Systems School of Engineering, London South Bank University, 103 Borough Road, London SE1 OAA, UK, Tel: 02078157569,

E-mail: xiaop@lsbu.ac.uk

Keywords: Capacitive contact imaging, Skin damage assessments, Skin hydration, Skin occlusion, Transepidermal water loss.

ABSTRACT

Water in the skin, particularly in the outmost skin layer-the stratum corneum, plays a key role in the skin's barrier functions as well as its cosmetic properties. However, the water distribution within the skin is not uniform, and to measure the water in the skin is very difficult. Although there are many skin hydration measurement instruments on the market, e.g. Corneometer (Courage+Khazaka electronic GmbH, Germany), DermaLab hydration probe (Cortex Technology, Denmark), MoistureMeter (Delfin Technologies, Finland), Moisture Checker (Scalar Corporation, Japan) and HydraTest (BeautyPro, UK) etc. their performances have left a lot to be desired. No technology can make accurate, absolute water content measurements, and no technology is imaging based.

INTRODUCTION

Capacitive fingerprint sensors, originally designed for biometric applications, have demonstrated capabilities for skin hydration imaging, skin surface analysis, 3D skin surface profiles, skin micro-relief as well as solvent penetration measurements in previous studies [1-6]. Comparing with other existing measurement technologies, capacitive contact imaging has a number of novelties, it is imaging based, it works on skin, hair and nail, and through proper calibration you can make accurate, absolute water content measurements. This paper presents a short review of the research work carried out in our research group on capacitive contact imaging based on capacitive fingerprint sensors for skin measurements.

Measurement Apparatus

The capacitive contact imaging technology developed by our research group is based on Fujistu fingerprint sensor (Fujistu Ltd, Japan), which has a matrix of 256 × 300 pixels, with 50 µm spatial resolution per pixel [5-11]. The sensor has a measurement area of 12.8 mm × 15 mm, it basically generates capacitance images of the skin surface. In each image, each pixel is represented by an 8 bit grayscale value, 0~255. In the skin, water has a high dielectric constant (80) and dry skin has a very low dielectric constant (~1-5). As a result, the higher water content will generate higher capacitance readings, and therefore darker images. The lower water content will generate lower capacitance readings, and therefore lighter images. The fingerprint sensor has a detection depth of ~50 µm, which makes it ideal to measure the water in stratum corneum. Our capacitive contact imaging technology has evolved a few times over the years. **Figures 1-3** shows the current version of the technology-commercialized as Epsilon permittivity imaging system through Biox Systems Ltd, UK, and its measurement principle [12].

(1). Epsilon and the *invitro* stand.

(2). Epsilon and the *in-vitro* stand.

(3). Capacitive fingerprint sensor measurement principle**.**

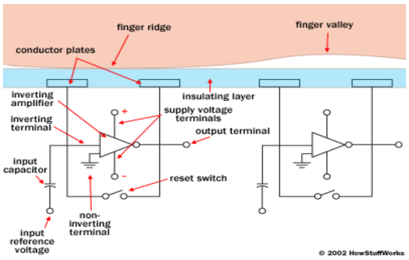


Figure 1-3. The Epsilon permittivity imaging system.

Applications

Skin hydration measurements

The most important application for the capacitive contact imaging is skin hydration imaging. **Figure 4** shows the typical capacitive images of two skin sites, palm and volar forearm, before and after a 5 minute hydration by applying a soaking wet tissue on skin [7,8]. The skin sites were carefully patted dry after soaking. The results show that skin images were getting darker immediately after the wet tissue application, indicating a higher water content, and then as skin gradually recovered under the ambient condition, the images became lighter and lighter. It is interesting to see that even after 20 minutes' recovery, the skin images still did not recover to exactly the same grayscale as before. The slightly lighter colour might indicate there is a drying effect caused by the wet tissue application [8].

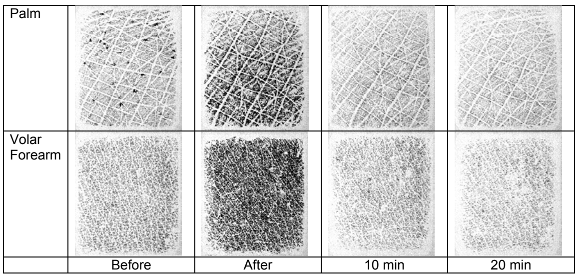


Figure 4. Capacitive images of two different skin sites, palm and volar forearm, before and after a 5 min wet tissue patch hydration.

By plotting the capacitive skin contact image in 3D, we can also study the skin surface profiles and skin texture, such as micro-relief lines, as illustrated [5] in **Figure 5.**

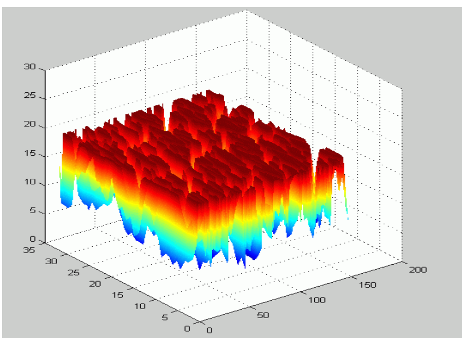
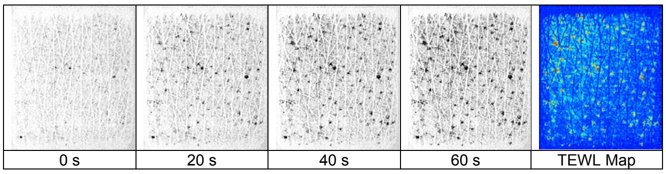


Figure 5. The 3D surface profiles of a typical capacitive skin image.

Skin Damage Assessments

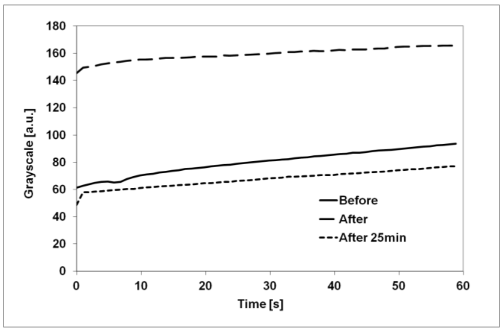
As a form of contact technology, the sensor reading increases as the contact time increases. **Figure 6** shows a typical set of images at different contact times. The results show that as the contact time increases, the skin images are getting darker, this is because the sensor blocked trans-epidermal water loss (TEWL) and caused water to accumulate on the skin surface. The black spots are the areas where water was actively coming out. One interesting application of this occlusion effect is to create a TEWL map, by calculating the differences of the first image and the last image of the contact period. TEWL map shows us where the water loss is actively happening on the skin surface [9].



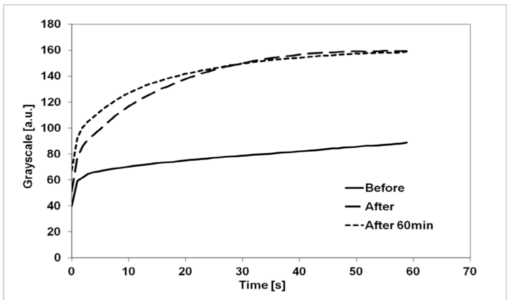
Capacitive skin images on a wrist skin site during a 1-minute occlusion measurements and the corresponding TEWL maps.

Figure 6. Capacitive skin images.

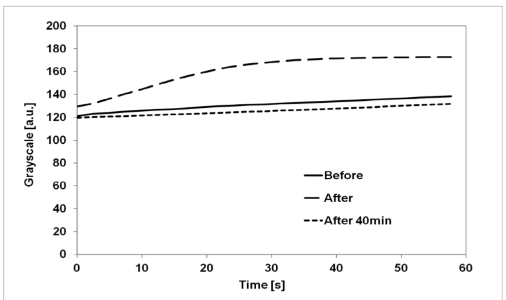
Another application of this occlusion effect is skin damage assessments. By comparing the time dependent grayscale occlusion curves, we can get the information about skin damages. Graph 1-3 shows the time dependent grayscale occlusion curves of different types of skin damages, i.e. (a) intensive washing; (b) tape stripping; and (c) SLS (Sodium Lauryl Sulfate) irritation. The results show that the shapes of the capacitive contacting imaging occlusion curves can be related to skin conditions, and different types of skin damages have different shapes of occlusion curves. The study also showed that the combination of skin occlusions using capacitive contact imaging and TEWL measurements can provide useful, complementary information about skin damage, and have potential as a new methodology for in-vivo skin damage assessments [11,13].



Graph 1. The time-dependent skin capacitive contact imaging occlusion curves of intensive washing.



Graph 2. The time dependent skin capacitive contact imaging occlusion curves of tape stripping.



Graph 3. The time dependent skin capacitive contact imaging occlusion curves of SLS irritation.

Skin Solvent Penetration

Because capacitive contact imaging is based on dielectric constant measurements, apart from water, it is also sensitive to many solvents that have relative high dielectric constant, such as dimethyl sulfoxide (DMSO), ethylene glycol, propylene glycol, propanol, glycerol, and alcohol etc. This makes it a potentially a very useful tool for studying solvent penetrations through membranes or the skin, and trans-dermal drug delivery [6,14,15].

Figure 7 shows an example of DMSO penetration through the skin. In this measurement, a small amount of DMSO solvent is applied to the volar forearm for a few minutes [14]. After the skin surface is wiped dry, tape stripping is then performed in order to understand the DMSO penetration. The measurements are performed both before and after the solvent applications, and after each tape stripping. The images can clearly show the DMSO penetration through the skin at different skin depth. By using the thickness information of each tape strip, we can also re-construct the above images into 3D solvent depth profiles as shown in **Figure 8.**

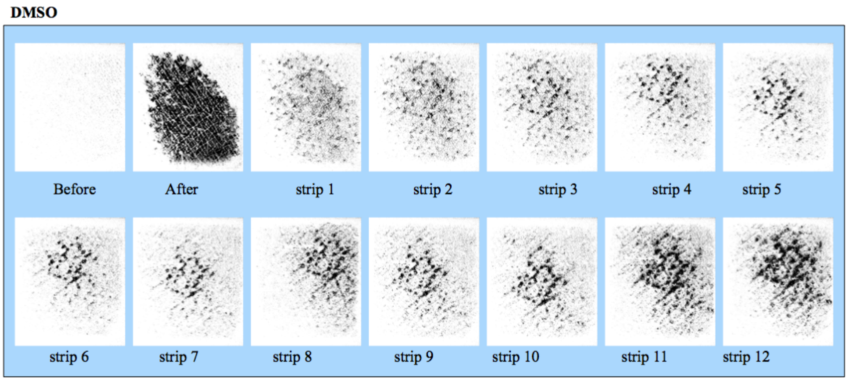


Figure 7. Fingerprint sensor images before and after DMSO application and subsequently during tape stripping.

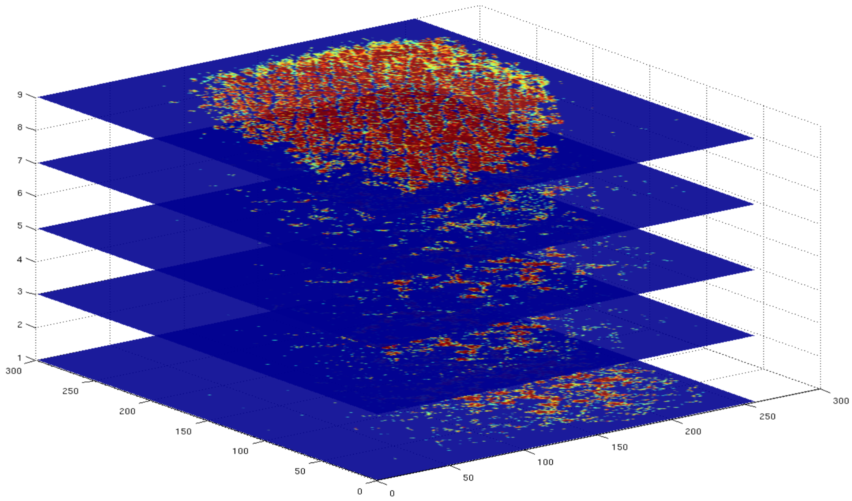


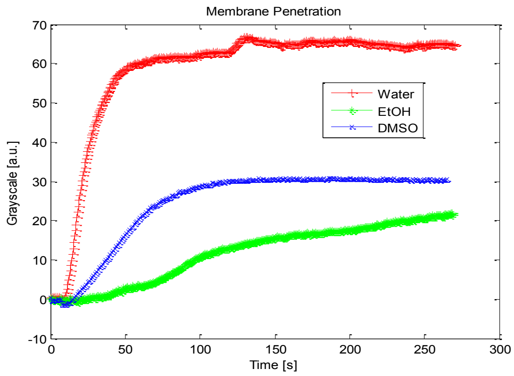
Figure 8. The corresponding 3D DMSO solvent concentration depth profiles through skin surface.

Membrane and in-vitro skin solvent penetration

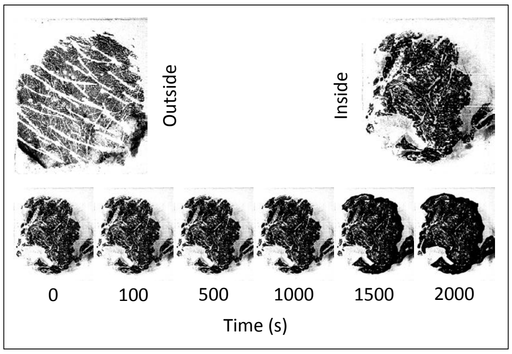
Apart from *in-vivo* skin, capacitive compact imaging can also be used for membranes and *in-vitro* skin samples [16,17]. In this case, a small piece of membrane or tissue was cut and placed on the sensor surface. A droplet of solvent was placed on the top of the sample. The sensor then recorded images continuously over a defined period of time. The time-dependent grayscale values of the images were then used for subsequent permeability analysis.

Graph 4 shows the time-dependent grayscale curves of solvent penetration through a silicone membrane (thickness ~80 µm). Three solvents were used, water, undiluted alcohol (EtOH) and undiluted dimethyl sulfoxide (DMSO), which have dielectric constants of 80, 24.3 and 46.7, respectively. The results showed that water penetrated through the membrane faster than EtOH and DMSO. EtOH is also expected to evaporate from the surface of the membrane and this may explain the lower profile for this solvent compared with the other solvents examined.

Figure 9 shows the capacitive images of outside and inside surface of porcine tissue, as well as the images at different times during water penetration. The outside porcine tissue image clearly shows the porcine skin surface texture and hairs. Graph 5 shows the corresponding time-dependent grayscale value curves for the images shown above. It is interesting to see there is a dog-leg effect at approximately 20 minutes (ca. 1200 seconds). This is likely due to the change of states of the water in porcine tissue, i.e. bound water to free water.

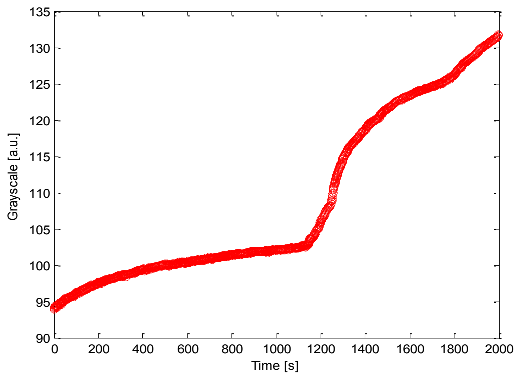


Graph 4. The time dependent grayscale curves of water, EtOH and DMSO images.



Capacitive contact images of the outside surface (top left), and the inside surface (top right) of in-vitro porcine tissue, and images of water penetration through the in-vitro porcine tissue (bottom) at different times (0-2,000 s)

Figure 9. Capacitive images of outside and inside surface of porcine tissue.



Graph 5. The corresponding time dependent grayscale value curves for the water penetration images.

Calibrations and comparison with other devices

By calibrating the capacitive sensor, we can get linear response to near-surface dielectric permittivity [18]. Calibration is done by measuring a number of chemical solvents with known dielectric constants, including air and water. By plotting the measured grayscale values against corresponding dielectric constants, we can get a capacitive sensor calibration curve, as shown in Graph 6. Because each capacitive sensor has slightly different electronic responses, each capacitive sensor will have slightly different calibration curves; therefore each capacitive sensor needs to be calibrated individually. Whence calibrated, the measurement results should be linearly dependent on dielectric constants, and should be independent of instruments. The calibration ensures consistency from instrument to instrument, and from time to time.

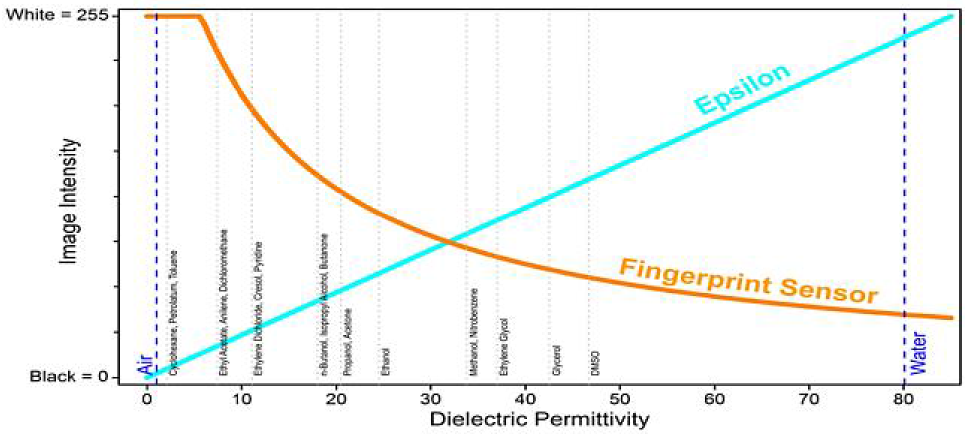
From the measured absolute dielectric constants of the skin, we can also work out the absolute water content in the skin by using following expression [19].

$$\varepsilon_{\mathrm{m}} = \varepsilon_{\mathrm{dry}} \mathrm{x} (1 - H) + \varepsilon_{\mathrm{water}} \mathrm{x\ H} \qquad (1)$$

Where ε_m is the measured dielectric constant, ε_{dry} is the dielectric constant of the dry skin, and ε_{water} is the dielectric constant of water, H is skin's water content in fractional percentage. Then we can work out the skin's water content using the measured dielectric constants, from Eq (1) we have,

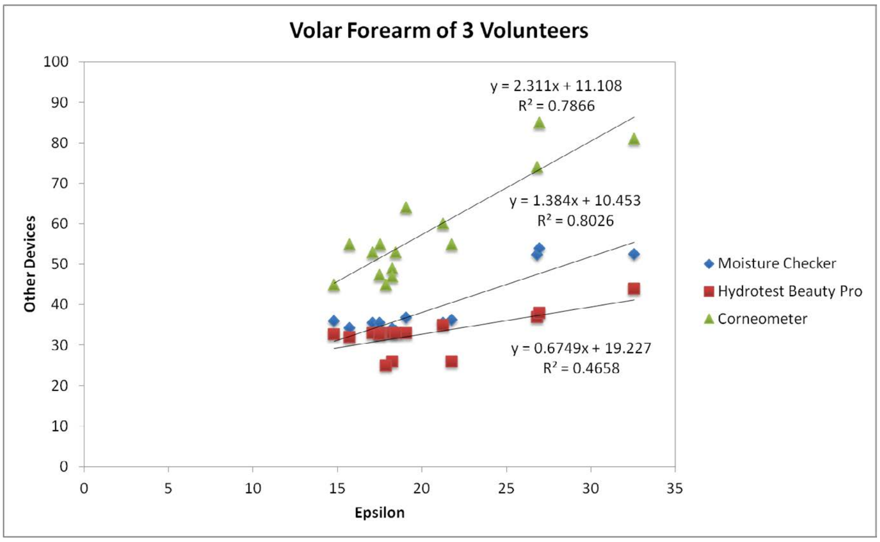
$$H = \frac{\varepsilon_{\mathrm{m}} - \varepsilon_{\mathrm{dry}}}{\varepsilon_{\mathrm{water}} - \varepsilon_{\mathrm{dry}}} \qquad (2)$$

Eq (2) can also be used for hair and nail measurements.

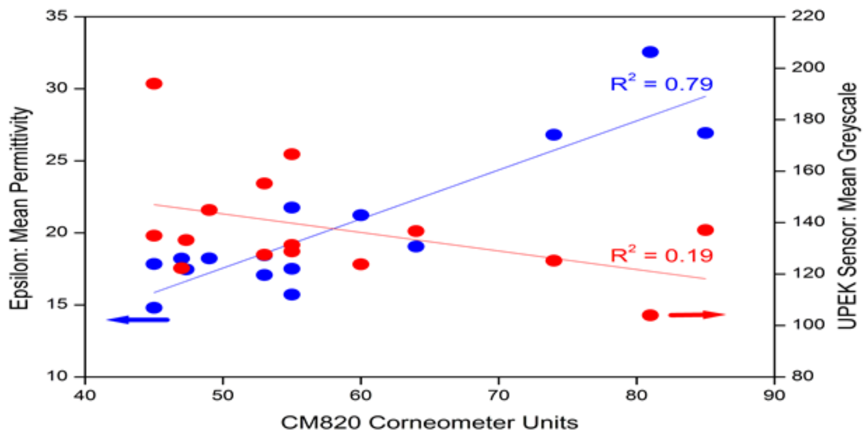


Graph 6. The calibration curve and linear response to dielectric permittivity.

Our study also compared the capacitive contact imaging with other skin measurement technologies, such as Moisture Checker, Hydrotest, Corneometer, as well as UPEK fingerprint sensor. As shown in Graphs 7 and 8. The results show that there is a general good correlation with other technologies, and particularly with Corneometer (R2=0.79).



Graph 7. The comparison results of Epsilon and Moisture Checker, Hydrotest and Corneometer.



Graph 8. The correlations between Corneometer and Epsilon as well as UPEK fingerprint sensor.

CONCLUSIONS

This paper presents a short review of skin capacitive contact imaging research work carried out in our research group. Our studies show that capacitive contact imaging based capacitive fingerprint sensors can be used for skin hydration imaging, skin surface analysis, 3D skin surface profiles, skin micro-relief as well as solvent penetration measurements in previous studies. It can work both on in-vivo skin and in-vitro skin samples, as well as membranes. Through calibration we can measure the absolute dielectric permittivity of the samples, and through dielectric constants we can calculate the absolute water content (or solvent content) in the samples. Capacitive contact imaging can be used for skin, hair and nail measurements.

REFERENCES

1. Léveque J and Querleux B. “SkinChip, A new tool for investigating the skin surface in vivo”. Skin Research and Technology. 2003;9:343-347.
2. Batisse D, et al. “Capacitance imaging of the skin surface”. Skin Research and Technology. 2006;12:99-104.
3. Bevilacqua A and Gherardi A. "Age-related skin analysis by capacitance images," in ICPR 2004. Proceedings of the 17th International Conference on Pattern Recognition. 2004;703-706.
4. Bevilacqua A and Gherardi A. "Characterization of a capacitive imaging system for skin surface analysis," in IPTA 2008. First Workshops on Image Processing Theory, Tools and Applications. 2008;1(7):23-26.
5. Singh H, et al. “In-vivo Skin Imaging For Hydration and Micro Relief Measurements”. Stratum Corneum V, Cardiff. 2013;114:287-289.
6. Ou X, et al. In-Vivo Skin Capacitive imaging Analysis by using Grey Level Co-occurrence Matrix (GLCM). International Journal of Pharmaceutics January. 2014;460:28-32.
7. Xiao P, et al. "Opto-thermal In-vivo Skin Hydration Measurements-A Comparison Study of Different Measurement Techniques". Journal of Physics Conference Series. 2009;214:1.
8. Xiao P, et al. ”Stratum Corneum Barrier Function Measurements by Using Contact Imaging and Condenser TEWL Method”. SCUR Meeting. 2012;23-25.
9. Xiao P, et al. ”In-vivo Skin Occlusion Study by using Photo-thermal Radiometry, Fingerprint Sensors and AquaFlux, Skin Forum UK, Versailles, France. 2009;9-10.
10. Pan W, et al. "The Occlusion Effects in Capacitive Contact Imaging for In-vivo Skin Damage Assessments". International Journal of Cosmetic Science. 2015;37:395-400.
11. Imhof RE, et al. "Closed-chamber transepidermal water loss measurement: microclimate, calibration and performance". International Journal of Cosmetic Science. 2009;31:97-118.
12. http://computer.howstuffworks.com/fingerprint-scanner3.htm.
13. Imhof RE, et al. “New Instrument for Measuremnet Water Vapour Flux Density from Arbitrary Surfaces”. IFSCC Magazine. 2002;4:397-301.
14. Xiao P, et al. ”In-vivo Trans-Dermal Drug Delivery Study by Using Capacitive Fingerprint Sensors, Skin Forum UK, Frankfurt, Germany 2011;28-29.
15. Xiao P, et al. “In-vivo Skin Solvent Penetration Measurements Using Opto-thermal Radiometry and Fingerprint Sensor”. International Journal of Thermophysics. 2012;33:1787-1794.
16. Xiao P, et al. “Membrane Solvent Penetration Measurements Using Contact Imaging”. Book chapter Advances in Dermatological Science. 2014;355-360.
17. Klang v, et al. “Skin integrity testing and monitoring of in vitro tape stripping by capacitance-based sensor imaging”, Skin Res. Tech 2012;19:e259-272.
18. Pan W, et al. "Skin Hydration Measurement Using Contact Imaging". SCC Showcase, New York, December 2014;11-12.
19. Xiao P and Bontozoglou C. ”Capacitive contact imaging for in-vivo hair and nail water content measurements. H and PC Today 2015;10:62-65.