Stratum Corneum Hydration Measurement using Capacitance Contact Imaging

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1. INTRODUCTION

Recent research has shown that biometric fingerprint sensors that respond to capacitance changes associated with touch can also be used for characterising static and dynamic skin properties including hydration, microrelief and solvent penetration [1-4]. With a typical spacial resolution of 50µm and a depth resolution of ~20µm, such contact imaging sensors are well matched to the characteristic dimensions of stratum corneum (SC) and hair.

However, whilst such sensors are excellent for visualisation, their measurement performance is limited by their non-linear response, chip-to-chip and pixel-to-pixel variability. Linearisation and calibration are therefore essential to ensure that quantitative image evaluations are meaningful and consistent from instrument to instrument and from time to time.

The Epsilon Model E100 (Biox Systems Ltd, England) is currently the only instrument with a linearised and calibrated response. By contrast, an otherwise similar contact imaging instrument (MoistureMap Model MM100, CK Technology sprl, Belgium) can only be used to give a qualitative indication of hydration heterogeneity, with the manufacturer recommending that the Corneometer® (Courage + Khazaka GmbH, Germany) be used for measurement.

2. LINEARISATION AND CALIBRATION

The native response of fingerprint sensors is non-linear and variable, as illustrated by the solid (typical) and dotted (sensor to sensor & pixel to pixel variations) grey lines in **Figure 1** below.

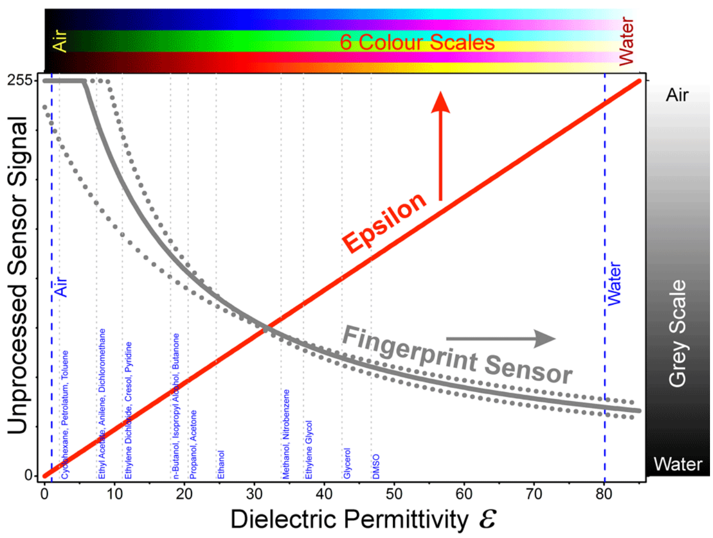


Figure 1: Native capacitance response (grey) and calibrated permittivity response (red) of a typical fingerprint sensor.

The Epsilon uses dielectric permittivity (dielectric constant, ε) for calibration. This is because dielectric permittivity is a material property where several solvents and other materials (see **Figure 1** for examples), are readily available for use as reliable calibration reference materials. By contrast, capacitance is a device property without independent definition.

3. EPSILON HARDWARE

The Epsilon Model E100 shown in **Figure 2** is the only capacitance contact imaging system on the market with a linear and calibrated response that enables it to measure SC hydration.

Figure 2: Epsilon Model E100 for in-vivo and in-vitro measurement.

Its hydration measurement capability has been verified by correlation with a Corneometer Model CM820, where correlation coefficients of R=0.97 (in-vitro) and R=0.89 (in-vivo) were found [5].

4. HYDRATION UNITS OF MEASUREMENT

At present, the Epsilon measures hydration using its calibrated dielectric permittivity scale rather than some arbitrary scale such as Corneometer Units. This works because the dielectric permittivity of water is much higher ($\varepsilon \sim 80$) than that of other constituents of skin. A more convenient *Hydration Index* scale is currently being assessed.

5. STATIC HYDRATION MEASUREMENT

The Epsilon can measure SC hydration with greater accuracy and flexibility than conventional single-sensor probes such as the Corneometer. Both the Epsilon and the Corneometer use the same capacitance measurement principle. Both the Epsilon and the Corneometer have ~20µm sensing depth that confines the measurement predominantly to the SC. However, the Epsilon has 76800 sensors whereas the Corneometer has one. That's a game-changer because skin is heterogeneous and skin-sensor contact is variable. The examples below illustrate this.

5.1. HYDRATION HETEROGENEITY ASSESSMENT

Epsilon images provide a revealing visualisation of hydration distribution in the vicinity of the site of interest. These images can be processed to give quantitative measures of heterogeneity as either Standard Deviation or Coefficient of Variation (CV%), or visually as histograms. This is illustrated with a volar forearm image in **Figure 3**.

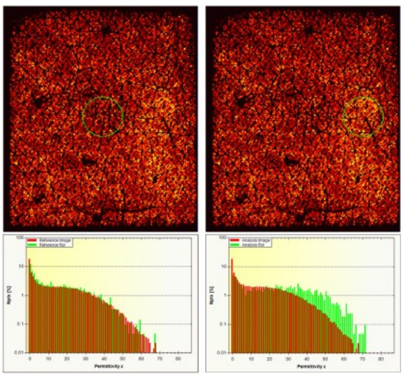


Figure 3: These two images are the same, but with the 2.6mm diameter green Region of Interest (*RoI*) circle displaced by a horizontal distance of 3.8mm.

The colour-co-ordinated histograms indicate hydration distribution for both the whole image (red) and the *RoI* (green).

The mean hydration within the left *RoI* is close to that of the whole image, with a dielectric permittivity of ε ~15 and a CV~90%. The mean hydration within the right *RoI* is clearly higher, with a dielectric permittivity of ε ~24.4 and a CV~70%. From these data, the hydration of the two *RoI*s differ by more than 60%!

5.2. CORRECTION FOR SKIN-SENSOR CONTACT

The Epsilon software has a powerful ε -filter to correct for bad contact between the sensor and skin. Bad contact may be due to microrelief or wrinkles, hair or other obstructions. The example in **Figure 4** illustrates how this works.

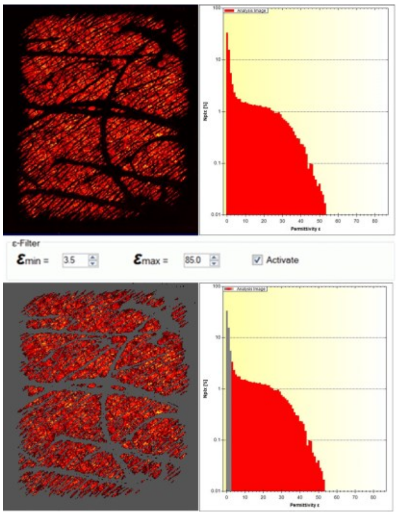


Figure 4: Hairy male ventral forearm, where the bad contact shows up as black, ie low ε of hair and air. The histogram (NB: Log scale) indicates bad contact by the prominent peak at low ε.

The ε -filter allows you to remove both low and high ε pixels.

This shows the effect of filtering pixels with ε -values below 3.5. Filtered pixels are shown in grey. The ~43% of pixels that remain give more accurate skin hydration information (ε =18.1) than the unfiltered image (ε =8.3).

5.3. CORRECTION FOR SKIN SURFACE WATER

Skin surface water can be a problem when measuring hydration (i) in the vicinity of mucous membranes, on occluded or damaged skin, (ii) in the presence of water-containing topical products, or (iii) in the presence of imperceptible perspiration or sweat. Skin surface water is not hydration, but its presence will falsify hydration readings of conventional instruments. **Figure 5** illustrates how the ε -filter can deal with skin surface water.

The image on the left is of the second joint of a male left thumb. Its main feature is a size mismatch between the skin contact area and the sensor. However, the non-contacting pixels (76% of the total) have been removed by the ε -filter described above, as indicated by the dark grey colouring. For the remaining pixels, the mean hydration is ε ~21.1 with a CV ~60%.

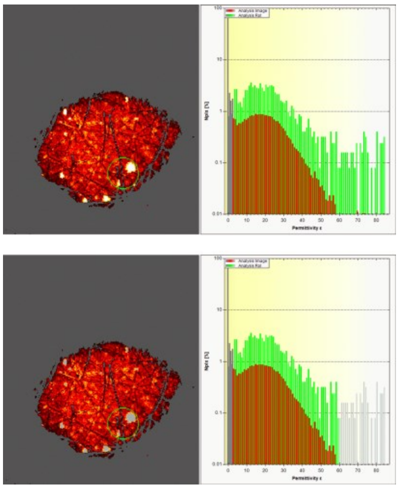


Figure 5: The yellow/white spots are surface water from imperceptible perspiration. The 2mm diameter green *RoI* encloses an area where surface water predominates. Within this *RoI*, the mean permittivity is considerably higher (ε ~27.8, CV ~78%) than for the whole area of contact.

Here the surface water has been filtered out for ε -values above 60, as indicated by the light grey colour in the image and histogram. For the whole contact area, this filter changes the mean ε from 21.1 to 20.1. For the *RoI*, the change is from 27.8 to 21.3.

In this example, the surface water alone produced a ~5% measurement error for the whole contact area and a ~23% measurement error for the *RoI*.

6. DYNAMIC OCCLUSION MEASUREMENT

The Epsilon system can be used to study time-dependent phenomena by recording short bursts or long videos. This is illustrated in **Figure 6** below with a study of occlusive surface water accumulation in a tape stripping experiment. Scotch tape was used on a volar forearm skin site, repeatedly stripping the same site. Epsilon bursts (60 second total duration @ 1 frame per second) were recorded on the intact site and after every second strip.

Occlusion by contact between the skin and the Epsilon sensor during the 60 second burst measurements causes the TEWL to be trapped as skin surface water. Trapped skin surface water causes the dielectric permittivity to increase, which shows up in the images as a colour change from dark red through to yellow.

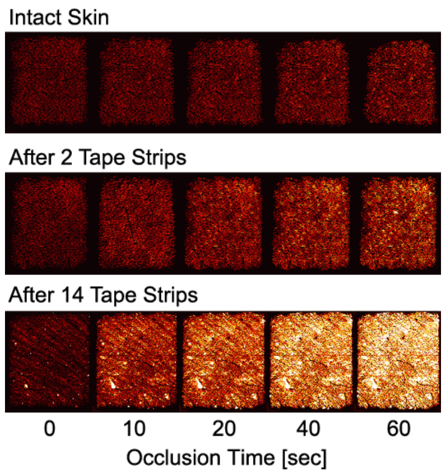
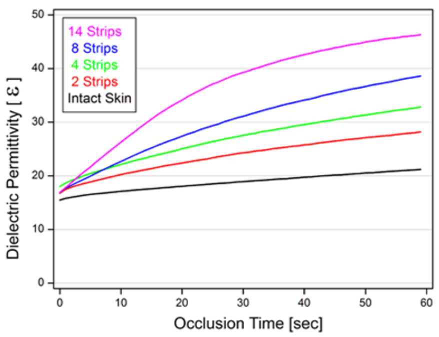


Figure 6: Shown here are example images from the recorded bursts. Note that significant barrier damage becomes visible after just 2 strips, as indicated by the increased rate of surface water accumulation compared with intact skin. Also, the barrier damage after 14 strips is highly heterogeneous, with the bright yellow areas indicating greater than average damage.



These occlusion plots were calculated as whole-image averages. They clearly show (i) an almost unchanged hydration at t=0, irrespective of the number of strips removed, and (ii) increased barrier damage with number of strips removed.

7. SUMMARY

Hydration measurement using contact imaging is more accurate, more versatile and faster than corresponding measurements with single-sensor instruments such as the Corneometer. More accurate because measurement errors associated with less than perfect contact and skin surface water can be eliminated using post-measurement image processing. More versatile because it can be used on less than ideal skin sites such as hairy skin, unshaven scalp, wrinkly skin, skeletal joints and other curved skin areas. Faster, because mean hydration and hydration heterogeneity in multiple regions of interest can be assessed simultaneously in the same image.

REFERENCES

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