Skin Hydration Measurement Using Contact Imaging

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1. INTRODUCTION

Capacitive silicon fingerprint sensors, originally designed for biometric applications, have shown potential for contact imaging of skin properties including hydration, micro-relief analysis [1-3], as well as solvent penetration measurements [4].

In this poster, we present a study of in-vivo skin hydration measurements using a commercial contact imaging system, the Epsilon Model E100 (Biox Systems Ltd, England). We first present the theoretical background and measurement principles to illustrate how the Epsilon response is linearised and calibrated. We then present measurements to illustrate how the software can capture and process images to reduce the measurement artefacts of (i) inconsistent contact, (ii) hair, (iii) micro-relief & wrinkles and (iv) surface water from imperceptible perspiration. Finally, we measure Epsilon - Corneometer (Courage + Khazaka GmbH, Germany) correlations both in-vitro and in-vivo.

2. THE EPSILON PERMITTIVITY IMAGING SYSTEM

The Epsilon permittivity imaging system is illustrated in **Figure 1**.

Figure 1: The Epsilon Permittivity Imaging System.
Left: Hand-held probe and parking stand. Right: In-vitro stand.

The instrument uses a Fujitsu fingerprint sensor (Fujitsu Ltd, Japan), which has 76800 pixels arranged in a 256x300 rectangular array with 50µm spacing. Each pixel is a capacitive sensor, which responds to the dielectric constant or permittivity of the sample in contact with its sensing surface. The native sensor response is digitised with 8-bit (0-255) resolution.

3. LINEARISATION AND CALIBRATION

The Epsilon differs from other such devices (SkinChip®, L'Oréal, France; MoistureMap, CK Technology sprl, Belgium) in its linear and calibrated response to near-surface dielectric permittivity (ε). The native response of a typical fingerprint sensor is non-linear, as illustrated by the orange line of **Figure 2**. At low ε, the readings can be off-scale, producing a uniform white background, even when the sensor surface is dirty. At high ε, the response is non-linear, with progressively decreasing sensitivity. This causes fingerprint lines to be imaged with a consistent dark grey colour for a wide range of skin hydration values. Therefore, fingerprint sensors are good for fingerprinting, but less than good for quantitative imaging. The linearised response (blue line of **Figure 2**) is achieved by (i) altering sensor operating parameters to keep the readings on-scale for the entire ***Ɛ***-range of interest and (ii) mapping the resultant output onto a linear scale by means of a mathematical model of the sensor's characteristics.

After linearisation, the sensor is calibrated to ensure consistent measurements from instrument to instrument and from time to time.

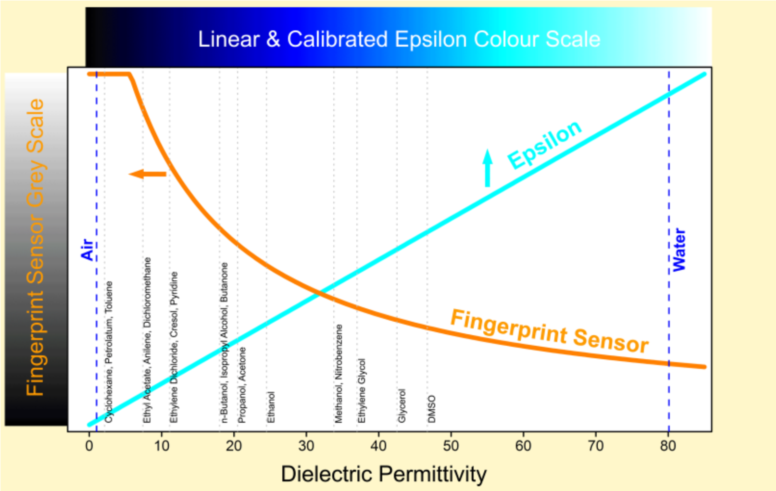

Figure 2: The Epsilon maps the native fingerprint sensor response (orange line) onto a linear and calibrated permittivity response (blue line).

4. EPSILON IMAGE PROCESSING

The Epsilon software offers several image processing features to extract information from measurements. The most basic is *Region of Interest* (*RoI*), where user-defined circular areas can be analysed separately, alongside similar analyses of the whole image. **Figure 3 (Left)** shows an analysis of a single image, where the ***Ɛ***-histogram of the whole image (green) is distinctly different from that of the *RoI* (red). **Figure 3 (Right)** shows an analysis of a timed image sequence recorded as a user-defined burst, where mean ***Ɛ*** changes for the whole image (green) follow the same trend as the *RoI* (red).

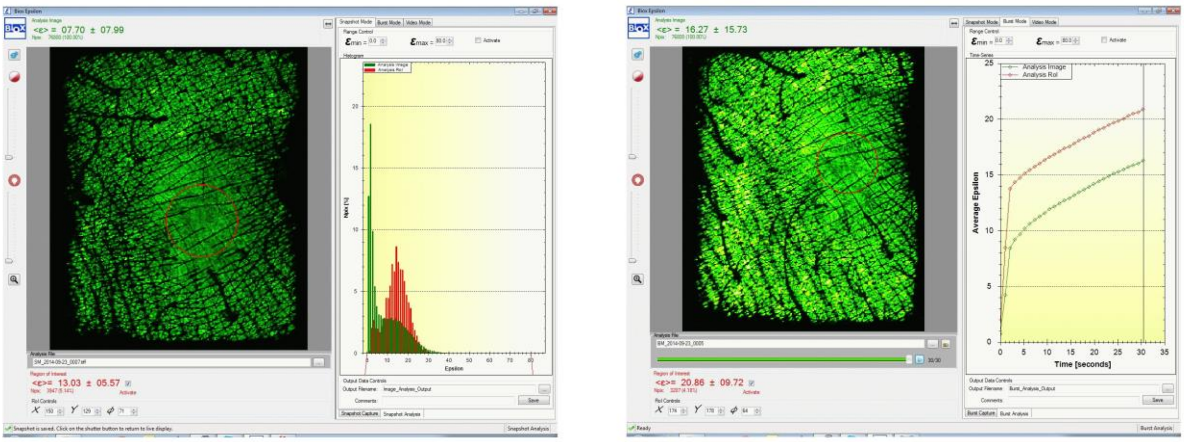

Figure 3: Full image & RoI analysis.
Left: Snapshot Mode. Right: Burst Mode.

The main image processing technique for hydration measurement is the ***Ɛ****-filter*, where thresholds can be set to remove measurement artefacts associated with low ***Ɛ*** (bad contact) and high ***Ɛ*** (surface water). In **Figure 4 (Left)**, the low ***Ɛ*** dark area around the periphery is due to bad contact and the high ***Ɛ*** bright spots are surface water at sweat gland openings. The action of the filter is clearly visible in **Figure 4 (Right)**, where the removed pixels are indicated by the dark and light grey areas for low and high ***Ɛ*** respectively.

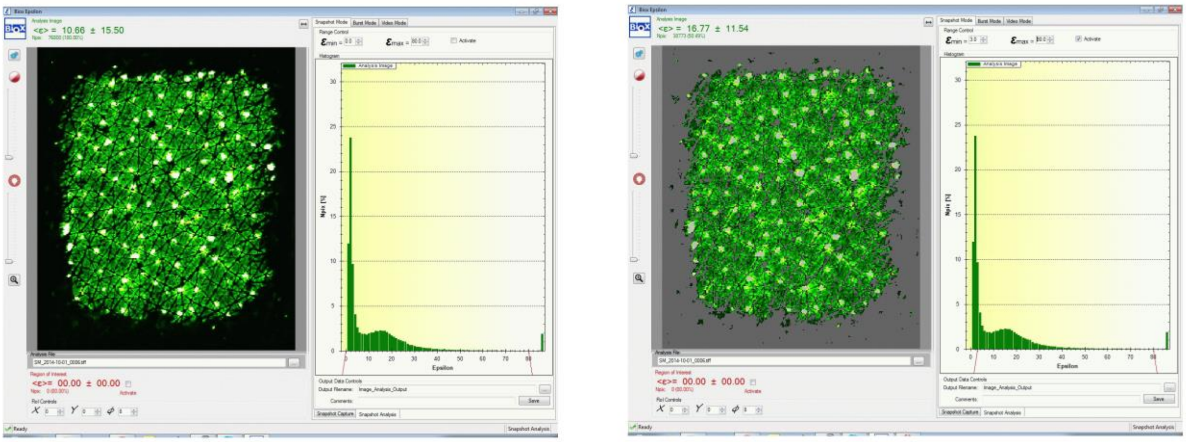

Figure 4: Volar forearm image showing spots of surface water at sweat gland openings.
Left: Unprocessed image. Right: *Ɛ*-filtered image where the removed pixels show as dark and light grey areas.

Another important aspect of hydration measurement is contact time, where there is a trade-off between contact settling and occlusion. The Epsilon software provides powerful and flexible means to measure the effect of contact time by recording image bursts, see **Figure 3 (Right)** for example. Once the optimum contact conditions are established, routine measurements can be performed with single-image recording using the *Event Triggering*, *Delay Time* and *Averaging* functions, see **Figure 5 (Left)**.

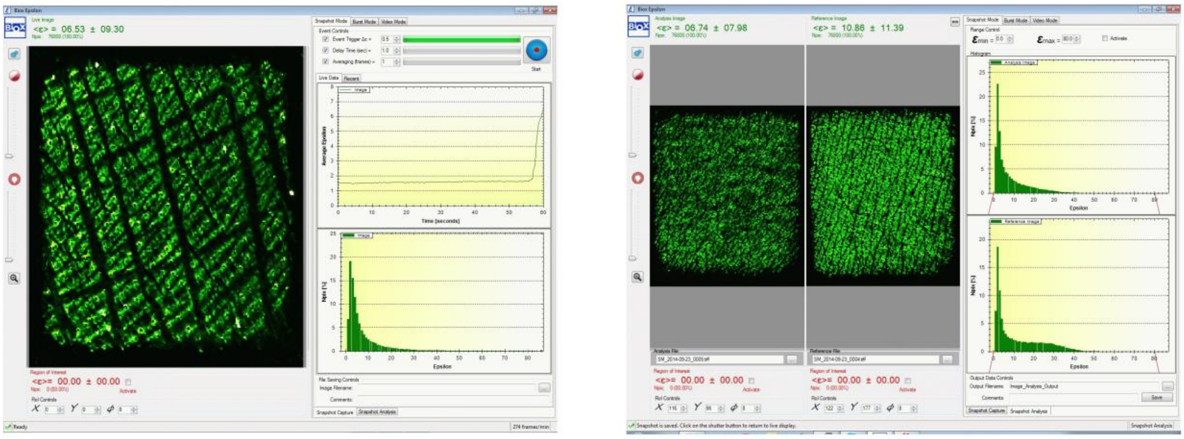

Figure 5: Left: Epsilon image capture controls. Right: Side-by-side comparison of two images. The left image is untreated skin and the right image is an adjacent site treated with a moisturizing cream.

Finally, the Epsilon software provides an image comparison feature. This is illustrated in **Figure 5 (Right)**, where two volar forearm images of (i) an untreated site (left image) and (ii) an adjacent site treated with a moisturizing cream (right image) are displayed side-by-side. In this case it is clear that the treated site has a higher mean ***Ɛ*** (ie it is brighter) and a more uniform contact with the sensor (ie it is smoother).

5. EPSILON – CORNEOMETER CORRELATIONS

Epsilon permittivity measurements were compared with Corneometer (Model CM820) readings using both in-vitro and in-vivo protocols.

The aim of the in-vitro comparison was to test the linearity of the Epsilon's response to sample permittivity. The Epsilon and the Corneometer use similar capacitive sensing methods and should therefore respond in similar ways to materials of differing permittivity. The comparison used a number of solvents (water, Propylene Glycol, Butanol, Heptanol, Decanol) and air in direct contact with the sensors. The solvent layers used were thick enough to ensure that the electric fields from the sensors were fully contained within them. For the Epsilon, a central region of the sensor was used, together with a *Region of Interest* to exclude areas of the sensor not covered by the solvents. For the Corneometer, the entire 7mm square sensor area was covered with solvent. The results are presented in **Figure 6 (Left)**.

For the in-vivo measurements, volar forearm skin sites of three healthy volunteers (20 – 30 years old) were hydrated for 30 minutes by contact with wet tissue paper, after which they were patted well dry. Measurements were performed at baseline and 0, 10, 20 and 30 minutes after patting dry. The results are presented in **Figure 6 (Right)**.

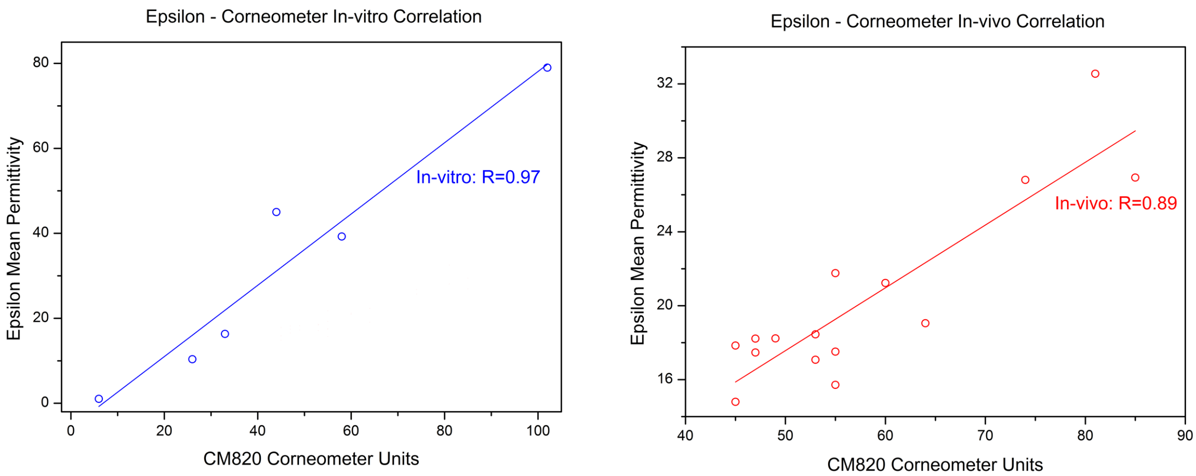

Figure 6: Epsilon - Corneometer Correlations.
Left: In-vitro correlation. Right: In-vivo correlation.

6. SUMMARY AND CONCLUSIONS

A correlation coefficient of R=0.97 was measured in the in-vitro Epsilon-Corneometer comparison experiment. This high value shows that the linearised permittivity response of the Epsilon maps convincingly onto the capacitance response of the Corneometer.

The in-vivo skin hydration measurements were found to correlate plausibly with side-by-side Corneometer measurements. The measured correlation coefficient of R=0.89 was found to be almost identical to a SkinChip-Corneometer correlation coefficient of R=0.88 reported in [5].

The main advantage of using contact imaging for characterising near-surface properties of heterogeneous materials is an ability, via software image processing, to reduce measurement artefacts. This was illustrated in this hydration study by the use of an ***Ɛ**-filter*, to exclude pixels associated with (i) inconsistent contact, (ii) hair, (iii) micro-relief & wrinkles and (iv) surface water from imperceptible perspiration.

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