Can the sub-THz image of skin be the new fingerprint? Visions in Biometrics

Yuri Feldman[1], Paul Ben Ishai[1], Haim Goldberger[2], Alexander Puzenko[2] and Ilya Gutman[1]
[1]The Hebrew University of Jerusalem, Jerusalem, 91904 Israel
[2]Neteera Ltd., Jerusalem, 91904, Israel

***Abstract*—The sub-THz reflectance of the Human palm was imaged while the person was subjected to varying degrees of stress. The pattern of individual pixel intensity and their correlation to stress matched the actual physical distribution of sweat pores on the hand surface. This fact is put forward as a possible novel biometric avenue.**

I. INTRODUCTION

The border today has become the first line of defense against an ever increasing number of threats. First and foremost stands the recognition of the individual attempting to enter the state. Integral to this is the concept of Biometric recognition as the guard against identity theft. While there are a number of visual methods possible, we present a new and exciting vista based on the distribution of sweat ducts and their response in the sub THz frequency range. For the last 8 years, it has become apparent that the Reflection Coefficient of the human skin in the frequency region 0.1 - 0.5 THz is governed primarily by the coiled structure of the sweat duct, allowing it to act as a helical antenna (See Fig.1) [1-5].

Frequently the registered spectra depend heavily on the physiological state of the individual. Succinctly put, should he be stressed then his reflection coefficient will indicate this by changes in both peak intensity and frequency. Furthermore, it appears that different origins of stress (mental, physical or emotional) will lead to different response in different frequency bands [6, 7]. This fact can be combined with the distribution of densities of sweat pores on the skin surface. While there are broad similarities between individuals (high density on the palms, low density on the arms for instance), inside those densities there is a unique pattern on the skin for each person [8, 9]. An example is on the palm of the hand, where the sweat pores follow quite closely the dips and ridges of the fingerprint. Coupled together, the existence of an informative spectra in the sub –THz frequency region and an individual spatial distribution of points on the body, one can imagine an image of the person in the sub – THz that is both unique and telling.

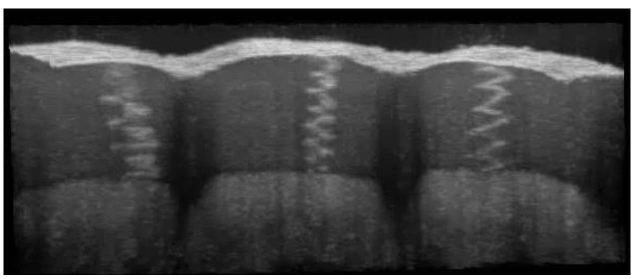

Fig. 1 - OCT imaging of the sweat ducts in upper epidermis of the human fingertip *in vivo* [2]**.**

The missing component in this vision is the necessary hardware. Because of the difficultly of electronic based detection and generation in the THz region of the spectrum – The Terahertz Gap [10-14]– most spectroscopic systems have been based on semi-optical gating methods using femtosecond pulsed lasers. These have been suitable for research and spectroscopy, but not for industrial application. Consequently, the penetration of THz to commercial and industrial applications has not greatly progressed. With the synergy of hot bolometric techniques for sub-THz detection [15], image processing and pattern recognition, there exists for the first time the possibility to create a system based on a sub-THz camera. This could effectively image the human skin, extract the unique pattern of the sweat duct activity on the surface, process this to a unique identity and all this done remotely. As a person cannot change his skin, this remote fingerprint exists no matter what. The implication of such a service for biometric identification at the border is very broad. Not only is the individual betrayed by his personal sweat pore distribution in the sub-THz regime, but also his mental state at that moment – is he aggressive or nervous? This opens a vista for selective questioning that until today were entirely subjective, depending only on the border control officer and his impressions.

We present evidence that the distribution of sweat ducts on the skin surface is individual. Furthermore, spatial variations in the sub-THz reflection coefficient over the body follow these individual patterns. As the intensity of reflection is also heavily influenced by the mental state of the individual, there is opened a unique opportunity in Biometric recognition. Not only can the individual be recognized remotely, but malicious intent can be detected too. The paper presents these possibilities and discusses the ramifications.

II. RESULTS

The palms of five subjects were filmed using a terahertz camera (TeraSense 1024, TeraSense Ltd.), while illuminated by a 100 GHz source operating at 50 mW. The illuminating beam was collimated to a diameter of 10 cm using a TPX lens (See Fig 2).

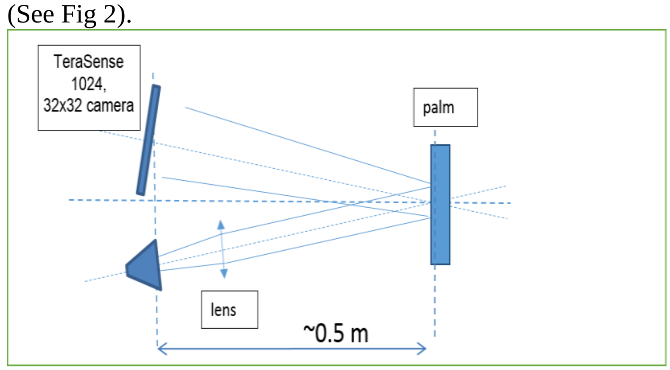

Fig. 2 – The experimental setup schematically represented.

Over the course of 11 minutes, the subjects were required to perform a number of mental and physical tests to induce differing levels of stress. The protocol is illustrated in Fig. 3. The time variations in the intensity of each pixel was correlated with a Galvanic Skin Response (GSR) reading of the individual. GSR is a recognized marker of subject stress. The individual pixel correlations where then used to create Correlation map of the subjects palm. Separately the position of individual sweat ducts on the palm of the subject were recorded by using iodine/starch staining. The darker the stain in the correlation image (Fig. 3(b)), the stronger the correlation with the GSR. The intensity of these "strong" pixels are presented for one of the subjects in Fig.3 (a), along the GRS trace and the stages of the protocol to induce stress. In Fig. 3(b) a comparison is made between the physical location of the sweat ducts for each subject and their respective sub-THz correlation maps. As can be seen the physical patterns of the sweat ducts are mirrored by the areas of strong correlation in the sub-THz.

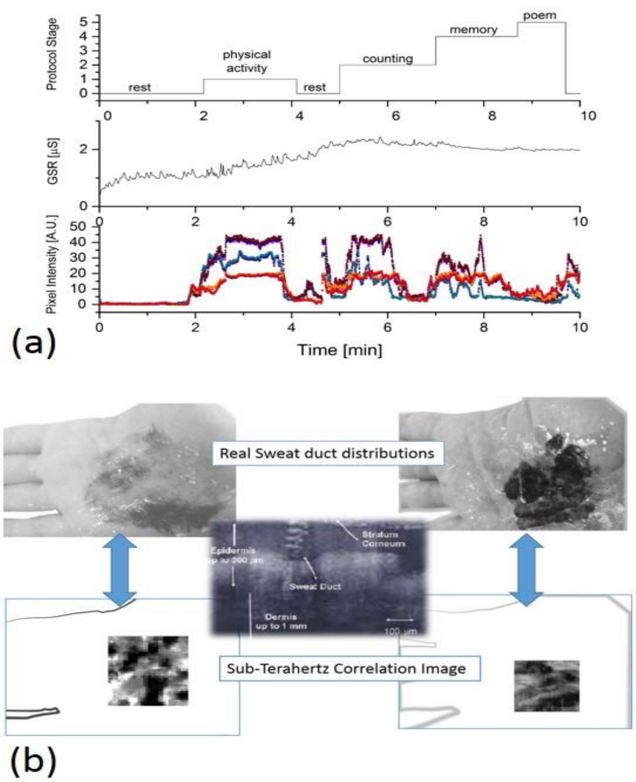

Fig. 3 – (a) The upper pane shows the time development of individual pixel intensity from a Terahertz camera, concurrently is shown the GSR trace of the subject and the measurement protocol describing the stress inducing tasks. The correlation is made between the individual pixel intensity and the GSR trace, as the reliable marker of physiological stress. The resulting correlation map is shown in pane (b), along with the real sweat duct distribution on the hand (iodine/starch staining). The coincidence between sweat duct density and maximum correlation is evident.

The coincidence between the two images can be evaluated by a 2D correlation matrix. Mathematically the problem can be reduced to searching for a matrix *X* of size *M* by *N* in a matrix *H* of size *P* by *Q*. The resulting correlation matrix *C* is of size *M+P-1* by *N+Q-1* and is defined by

$$C(k,l) = \sum_{m=0}^{M-1}\sum_{n=0}^{N-1} X(m,n)\overline{H}(m-k,n-1) \quad (1)$$

$$\text{where} \quad \begin{array}{c} -(P-1) \le k \le M-1 \\ -(Q-1) \le l \le N-1 \end{array} \quad (2)$$

and the bar indicates the conjugate matrix. Normalizing both images and then searching for the pixel correlation map inside the hand image (see Fig. 3) produces the 2D correlation matrix [16], graphically illustrated in Fig. 4

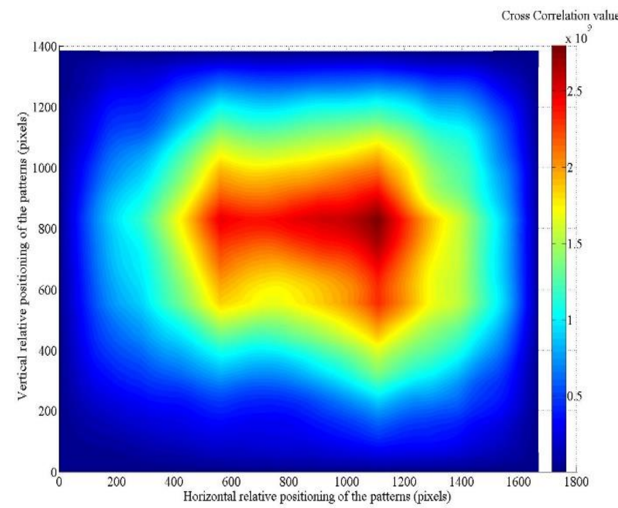

Fig. 4 – The 2D correlation matrix for subject 1 (left side of Fig. 3(b)). The map represents the coincidence of patterns visible in the Sub-THz Correlation Image (Fig. 3b) in the real sweat duct distribution images (Fig.3b). The darker red the color indicates the center of maximum correlation between the two.

From the correlation matrix of Fig. 4 the position of true overlap between the two images can be found can be found. The result for subject 1 is shown in Fig. 5.

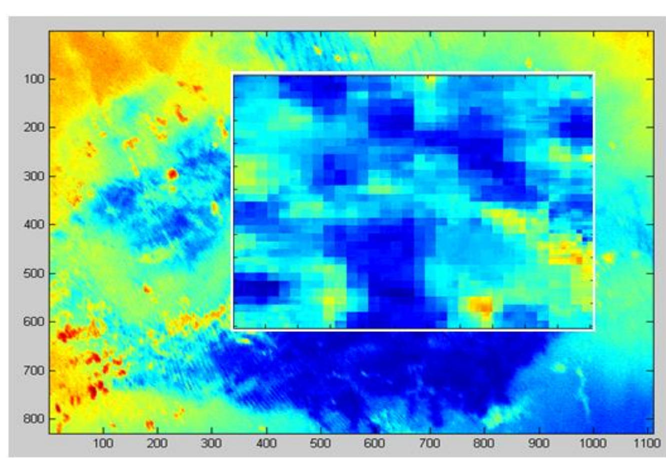

Fig. 5 – The Sub THz correlation Image (insert) overlain on the sweat pore distribution image, derived from the picture of the Iodine/Starch staining of the subject's hand (Fig. 3). The insert has been placed according to the 2D correlation map shown in Fig. 4. As can be seen the images match well.

The position of the sweat ducts has been shown to be unique and capable of being used as a finger print [17]. Consequently the pattern of sweating, when the subject is feeling stressed, should likewise be a unique feature to the individual. As has been suggested in ref. [2, 4], this activity leads to localized changes in the conductivity though the skin surface. In turn, this changes the localized reflection coefficient over the surface of the hand. One would expect that this spatially dependent reflection coefficient would reflect the variations of sweat pore density and activity on the surface of the skin. It is not too much of a jump to realize the intrinsic possibility for remote biometric applications.

III. SUMMARY

Mental activity, emotional stress or other such trigger of the autonomous nerve response [6, 7], will also result in the activity of our sweat duct system, a term usually referred to as "Non-thermal sweating". In turn, this activity leads to notable changes in the duct conductivity. It has already been shown that at these frequencies Electromagnetic energy is preferentially absorbed by the sweat duct [18]. Consequently, the reflection coefficient of the human skin in the sub – THz frequency band is heavily influenced by the sweat duct position and activity. Such an image can now be seen using a sub-THz camera. Furthermore, it was found that the sub-THz correlation image of sweat duct activity across the palm could be matched to the real position of sweat pores on the same palm. Due to the unique nature of the distribution of pores, this finding can be the basis of remote Biometric identification.

REFERENCES

[1] Y. Feldman, A. Puzenko, P. Ben Ishai, A. Caduff, and A. J. Agranat, "Human skin as arrays of helical antennas in the millimeter and submillimeter wave range," *Physical Review Letters,* vol. 100, p. 128102, Mar 28, 2008 2008.

[2] Y. Feldman, A. Puzenko, P. Ben Ishai, A. Caduff, I. Davidovich, F. Sakran, and A. J. Agrana "The electromagnetic response of human skin in the millimetre and submillimetre wave range," *Physics in Medicine and Biology,* vol. 54, pp. 3341-3363, JUN 7 2009 2009.

[3] I. Hayut, P. Ben Ishai, A. J. Agranat, and Y. Feldman, "Circular polarization induced by the three-dimensional chiral structure of human sweat ducts," *Physical Review E,* vol. 89, p. 042715, April 25, 2014 2014.

[4] I. Hayut, A. Puzenko, P. Ben Ishai, A. Polsman, A. J. Agranat, and Y. Feldman, "The Helical Structure of Sweat Ducts: Their Influence on the Electromagnetic Reflection Spectrum of the Skin," *IEEE Transactions on Terahertz Science and Technology,* vol. 3, pp. 207-215, 2013 2013.

[5] Y. Kurzweil-Segev, M. Brodsky, A. Polsman, E. Safrai, Y. Feldman, and S. Einav,"Remote Monitoring of Phasic Heart Rate Changes From the Palm," *Ieee Transactions on Terahertz Science and Technology,* vol. 4, pp. 618-623, Sep 2014.

[6] E. Safrai, P. Ben Ishai, A. Polsman, S. Einav, and Y. Feldman, "The Correlation of ECG Parameters to the Sub-THz Reflection Coefficient of Human Skin," *Ieee Transactions on Terahertz Science and Technology,* vol. 4, pp. 624-630, Sep 2014.

[7] E. Safrai, P. Ben Ishai, A. Caduff, A. Puzenko, A. Polsman, and A. J. Agranat,"The remote sensing of mental stress from the electromagnetic reflection coefficient of human skin in the sub-THz range," *Bioelectromagnetics,* vol. 33, pp. 375-382, JUL 2012 2012.

[8] N. M. Mathayya, *Human Physiology*, 3rd ed. New Delhi: Jaypee Brothers Publishers, 2002.

[9] S. Takagi and M. Tagawa, "Predominance of right-handed spirals in the interaepidermal sweat ducts in man and the primates," *The Japanese Journal of Physiology,* vol. 7, pp. 113-118, Jun 15, 1957 1957.

[10] J. B. Baxter and G. W. Guglietta, "Terahertz Spectroscopy," *Analytical Chemistry,* vol. 83, pp. 4342-4368, JUN 15 2011 2011.

[11] R. A. Lewis, "A review of terahertz sources," *Journal of Physics D-Applied Physics,* vol. 47, Sep 17 2014.

[12] I. Iniguez-de-La-Torre, C. Daher, J. F. Millithaler, J. Torres, P. Nouvel, and L. Varani, "Operation of GaN Planar Nanodiodes as THz Detectors and Mixers," *Ieee Transactions on Terahertz Science and Technology,* vol. 4, pp. 670-677, Nov 2014.

[13] R. Parthasarathy, T. Globus, T. Khromova, N. Swami, and D. Woolard, "Dielectric properties of biological molecules in the Terahertz gap," *Applied Physics Letters,* vol. 87, p. 113901, SEP 12 2005 2005.

[14] Y. Ueno and K. Ajito, "Analytical terahertz spectroscopy," *Analytical Sciences,* vol. 24, pp. 185-192, FEB 2008 2008.

[15] T. Morf, B. Klein, M. Despont, U. Drechsler, L. Kull, and D. Corcos, "Wide bandwidth room-temperature THz imaging array based on antenna-coupled MOSFET bolometer," *Sensors and Actuators a-Physical,* vol. 215, pp. 96-104, Aug 15 2014.

[16] J. N. Sarvaiya, S. Patnaik, and S. Bombaywala, "Image Registration by Template Matching Using Normalized Cross-Correlation," in *Advances in Computing, Control, & Telecommunication Technologies, 2009. ACT '09. International Conference on*, 2009, pp. 819-822.

[17] J. Lee, M. Pyo, S.-h. Lee, J. Kim, M. Ra, and W.-Y. Kim, "Hydrochromic conjugated polymers for human sweat pore mapping," *Nat Commun,* vol. 5, 04/29/online 2014.

[18] G. Shafirstein and E. G. Moros, "Modelling millimetre wave propagation and absorption in a high resolution skin model: the effect of sweat glands," *Physics in medicine and biology,* vol. 56, pp. 1329-1339, Mar 7, 2011 2011.