DEVELOPMENT OF A NEW MEASUREMENT METHOD FOR ERYTHEMA QUANTIFICATION

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Abstract: In dermatology several therapies are based on the beneficial effects of UV radiation. Erythema is the most common collateral effect associated with this therapies and can reduce their effectiveness. Its identification at early stage can be of great interest in therapies optimization. Its symptoms are a reddening of the skin, an increase in its temperature and edema. Presently only one of these symptoms is used in the erythema identification at a time, and its detection at early stage is quite difficult. The new approach proposed in this paper is the merging of the information extracted by the simultaneous observation of several phenomena in order to identify this inflammatory event at sub-clinical levels. Soft computing techniques are employed for the information fusion, in a knowledge based instrument able to classify the erythema level.

Introduction

In dermatological medicine several therapies are based on the beneficial effects of UV radiation. This kind of therapies can be successfully applied in the presence of skin disease, for example psoriasis, childish jaundice, vitiligo and some mycosis.

Erythema is the most common collateral effects associated with this type of therapies and its onset can reduce the effectiveness of the treatment. The possibility to identify and objectively quantify erythema level at early stage can be of great interest in the optimization of any phototerapic process.

Erythema is a skin inflammatory event characterised by vasodilatation and increased vessel permeability. The mainly produced effects are a reddening of the skin, an increase in its temperature and edema. These symptoms can be used in the identification of erythema.

Different instruments are employed in the quantification of erythema. Spectrophotometers and colorimeters [1, 2, 3, 4, 5, 6] are widely used to identify the associated reddening effect. Impedance analyser [7, 8] can handle changes in vessel permeability.

The innovative approach proposed is to exploit redundancy of information gathered by the simultaneous observation of several involved phenomena, which are the edema, the reddening and the temperature shift of the skin. The aim is to objectively classify this inflammatory event at a sub-clinical level. The principal components analysis (PCA) method has been used to verify the feasibility of this approach. The data fusion process has been realised by means of soft computing techniques in order to develop a knowledge-based instrument able to support operator to discriminate and classify the erythema level.

Materials and Methods

Figure 1 highlights which are the main symptoms (italics) associated with erythema and their causes.

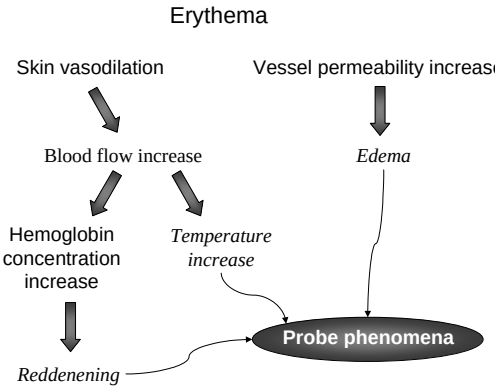

Figure 1: Erythema involved phenomena.

These symptoms are also the main candidates to become the probe phenomena in our approach. A change in the skin temperature due to an increasing blood flow in the erythematic area can be measured by means of an infrared sensor. As the black body is a good approximation of the skin behaviour in the IR region, a pyrometric method is adopted to measure the skin temperature. The main advantage of this approach is the possibility to perform a contactless measurement that minimises any disturbance effect due to the measurement process.

Hemoglobin concentration increase, consequent to skin vasodilatation, produce variation of the skin optical properties that were measured by means of a particular spectrophotometer. The availability of a skin-light interaction model allows us to extract information about skin components through reflectance spectroscopy.

Following the theoretical treatment of the optical

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properties of the skin developed by Dawson et al. [9, 10], skin reflectance has been measured at four different wavelengths. The information related to hemoglobin, chromophore that causes the reddening effect, and to melanin, pigment responsible of a masking effect on the reddening, was extracted from reflectance measurements through specific erythema indices [5, 6, 11]

$$E_1=\log(R(654)/R(558))$$
$$E_2=\log(R(621)/R(525)),$$

where $R(\lambda)$ rapresents an approximated measurement of skin reflectance at wavelength λ, and melanin index

$$M=\log(R(654)/R(621))$$

with similar notation.

The spectrophotometer light sources are four LEDs with peak emission wavelengths selected in function of the erythema and melanin indices. The radiation intensity sensor is a silicon photodiode.

The LEDs are driven with variable current to allow calibration on white surface assuring a compensation effect for the wavelength dependence of the photodiode spectral sensitivity.

The main part of the spectrophotometer is the probe where the conditioning circuit is located. It is a cylindrical structure (internal diameter 2.2 cm) with matt internal surface to minimise reflection. The probe (Figure 2) was designed in order to limit the skin's area to be analysed, to keep constant the distance between the skin and the detector and to minimise the influence of stray light.

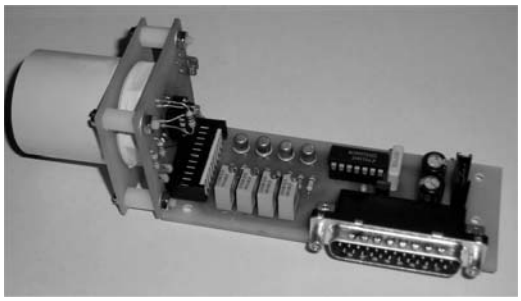

Figure 2: Picture of the spectrophotometer.

Edema is a change in the ratio between interstitial and intracellular fluids, a situation induced by vessel permeability increase. A basic understanding of mechanisms that lie on the origin of the skin's dielectrical properties allow to obtain diagnostic information through bioimpedance analysis, performed by means of an impedance analyser.

At low frequency (<10 kHz) the tissue impedance is mostly affected by interstitial fluid, but at higher frequency the bioimpedance depends on the sum of the inter- and intra- cellular fluid.

Thus, particular edema indices have been calculated from the data obtained from the HP4192A analyser in the range 5 Hz to 500 kHz. [7, 8]. A particular electrode layout was designed to minimise the influence of oriented skin cellular structures. In Figure 3 the circular concentric structure of the electrode is schematised.

Figure 3: Scheme of electrode.

Edema indices

$$MZ=|Z(100Hz)|/|Z(500kHz)|$$
$$FZ=\angle Z(500kHz)-\angle Z(100Hz),$$

where Z(f) represent the skin electrical impedance measured at frequency f, have been calculated from the value of the skin impedance at two different frequencies. These two frequencies resulted to be the most significant for this application after the observation of the behaviour of the bioimpedance as function of the frequency in the range 5 Hz to 500 kHz.

The developed instrument has been interfaced with the computer to get advantage from the virtual instrumentation flexibility. Figure 4 shows the control panel designed to run the spectrophotometer. Similar panels have been built to control the IR-sensor and the impedance analyser.

Results

Measurements have been performed on the skin of eight volunteers in two different conditions to validate the developed instrument. The first series of measurements have been done on the skin in physiological conditions; the second series have been done on the skin affected by pharmacological induced erythema.

Table 1: Experimental data obtained on a single subject.

	Conditions	
Indices	**physiological**	**pathological**
Temperature (°C)	27,3±0,1	28,5±0,1
E_1	0,153±0,006	0,213±0,001
E_2	0,124±0,004	0,186±0,001
M	0,062±0,001	0,064±0,001
MZ	405±5	742±5
FZ	14±2	33±2

ISSN: 1727-1983

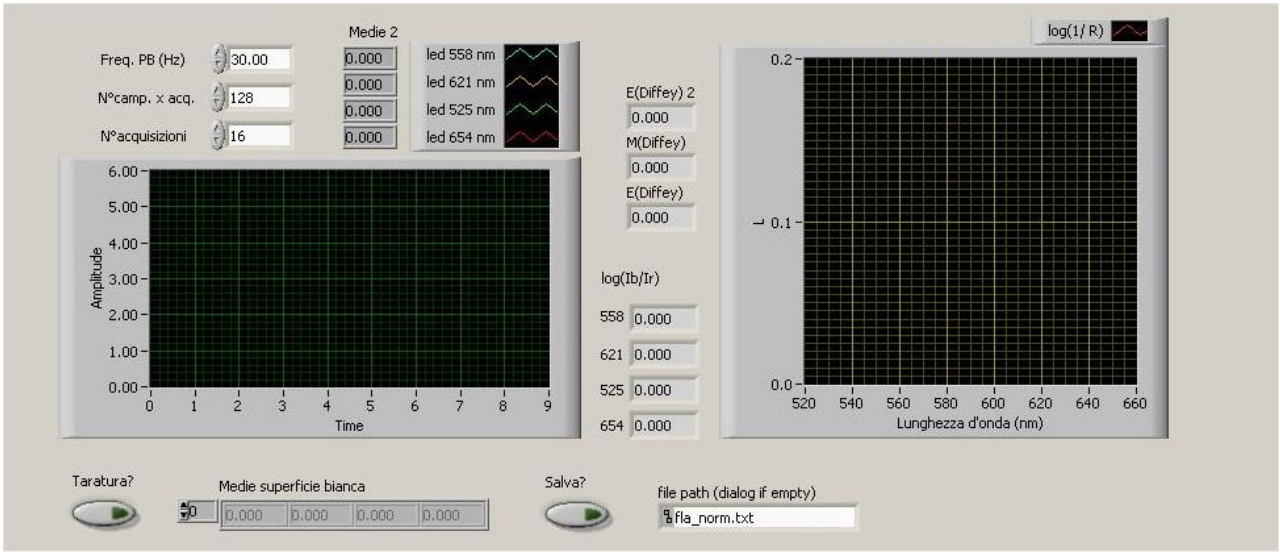

Figure 4: The virtual instrument: control panel.

Measurements on all subjects confirmed that during the passage from physiological to pathological conditions there is a skin temperature increase, a decrease in skin reflectance at wavelengths corresponding to the spectral absorption peak of haemoglobin and a change in skin tissue impedance.

Table 1 shows temperature, erythema and melanin indices and edema indices values measured on the forearm skin of one volunteer.

The principal component analysis method has been employed to merge information contained in the chosen indices in order to discriminate erythematic conditions.

Figure 5 represents measurements done on the skin of volunteers as function of the first two principal components; Figure 6 represents projection of the measurements space on the first and the third principal component. Figure 7 represents eigenvector coefficients (a_{i2}) relative to the second biggest eigenvalue in function of eigenvector coefficients (a_{i1}) relative to the biggest eigenvalue.

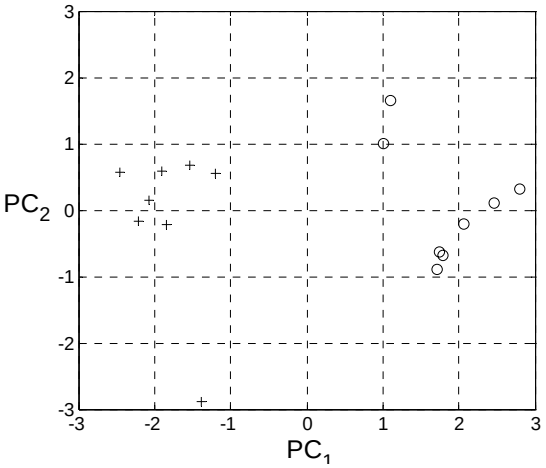

Figure 5: PCA's results: scores. Normal skin condition (+) and erythematic condition (o). PC1, PC2 are the first two principal components.

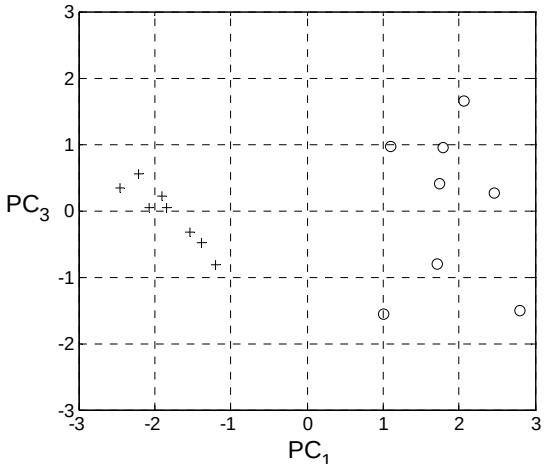

Figure 6: PCA's results: scores. Normal skin condition (+) and erythematic condition (o). PC1 principal components versus PC3.

Results of the principal component analysis on the experimental data show that the redundancy of information gathered with the proposed approach makes the system able to discriminate erythema. In fact in Figures 5 and 6 the dataset regarding the pathologic condition doesn't overlap the normal condition one.

The redundancy of the gathered information is confirmed with the Figure 7 where the data regarding temperature, erythema and edema indexes are positioned close each other. The melanin index, which is correlated with the skin type, is positioned well apart from the above-mentioned group and this gives us a further degree of freedom to make the instrument

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independent from the skin pigmentation level.

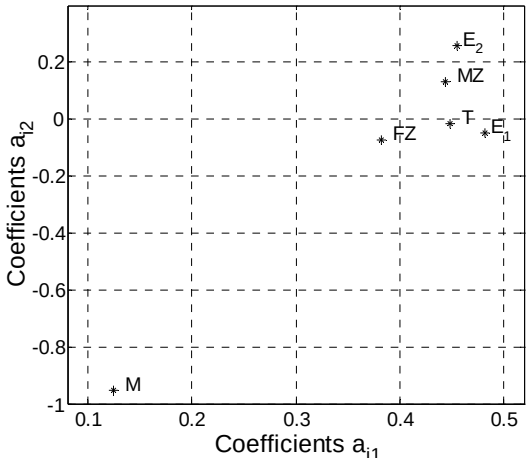

Figure 7: PCA's results: loadings. Distribution of the indices as function of coefficients a_{i1} and a_{i2} (first and second eigenvector coefficients respectively).

The Knowledge Based Instrument

A formalised global model of phenomena involved in erythema process is not available. Soft computing techniques allow to build up euristic models that are very often suitable for applications like the described one. Another important advantage of soft computing methods is their capability to realise tools able to emulate the human experts panels knowledge. In this way it's possible to support medical operators in diagnosis processes.

In order to achieve a system to support medical operators in subclinical erythema diagnosis and to classify the erythema in clinical status, fuzzy logic [12] has been chosen among soft computing techniques.

To realise the fuzzy system, for each input index and for the output erythema level, membership functions have been defined. As an example, temperature, E1 index and erythema level membership functions are reported in Figures 8, 9 and 10.

From the experimental data analysis and experts' knowledge, an important role of erythema index E1 has been observed. Nevertheless this alone factor is not enough to discriminate the erythematic condition at subclinical level. In fact an E1 range exists where it's not possible to perform a reliable diagnosis. In this case the diagnosis is supported by the information carried by the other parameters. The information fusion process is performed by the rules set reported in Table 2.

The fuzzy logic system was developed by Matlab Fuzzy Toolbox.

Conclusions

The principal component analysis shows that the use of multiple probe phenomena would increase the possibility to identify erythema at an early stage.

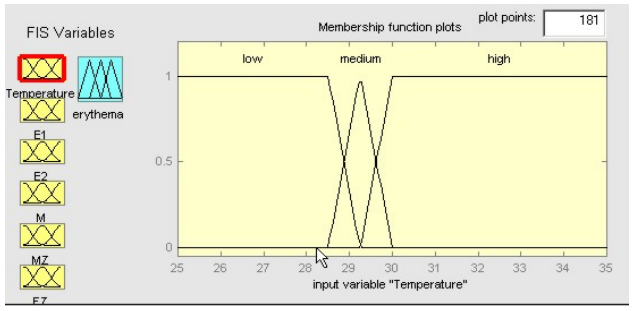

Figure 8: Membership function of the 'temperature index' input.

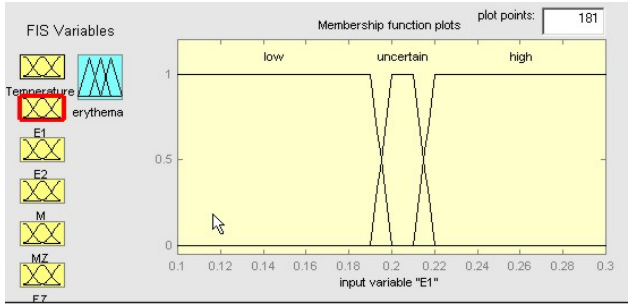

Figure 9: Membership function of the 'E1 erythema index' input.

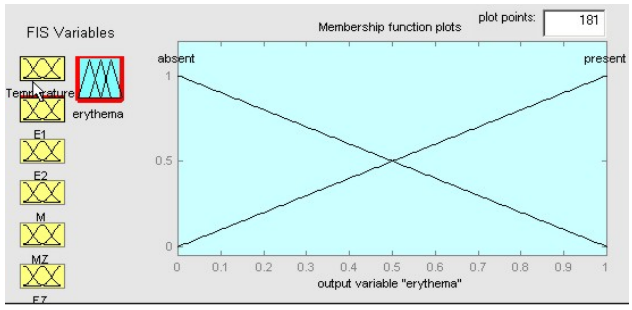

Figure 10: Membership function of the 'Erythema level' output.

The proposed approach is therefore useful to develop a knowledge-based instrument able to support medical operators in low-level erythema diagnosis. A fuzzy logic system has been developed and tested on a preliminary experimental data, demonstrating the proposed method feasibility. The next step shall be to collect more experimental data, with the aim to validate and optimize the knowledge-based system by neuro-fuzzy techniques.

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Table 2: Set of rules for 'erythema level' evaluation.

	Temp.		**E1**		**E2**		**MZ**		**FZ**		**Erythema**
IF		AND	low	AND		AND		AND		THEN	absent
			high								present
	low		uncertain		not high		not high		not high		absent
	not high		uncertain		low		not high		not high		absent
	not high		uncertain		not high		low		not high		absent
	not high		uncertain		not high		not high		low		absent
	high		uncertain		not low		not low		not low		present
	not low		uncertain		high		not low		not low		present
	not low		uncertain		not low		high		not low		present
			uncertain		not low		not low		high		present

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