A MODERN WEARABLE SYSTEM FOR THE DYNAMIC MONITORING OF THE SKIN THERMOGRAPHY: DESIGNING A SUITABLE SKIN-SENSOR INTERFACE

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Abstract: A practical, small-sized equipment with an adequate thermal resolution in the range of clinical interest has been developed. The hardware incorporates a sensor unit with a 16x16 Silicon Celsius precise sensor thermometer (odoscope unit), a multiplexing unit , a processing and conditioning unit , and the powering oscillation connecting and stabilization unit. A dedicated software permits a colour mapping reconstruction. We also set-up preliminary clinical tests on hand skin.

Introduction

Skin temperature is influenced by complex interactions between heat conducted through specific warming areas, blood flowing through the various skin layers, and the influence of the external environment [1].

The Thermal imaging of the skin has been used for several decades to monitor the temperature distribution of human skin. Abnormalities such as malignancies, inflammation, and infection cause localized increases in temperature which show as hot spots or as asymmetrical patterns in an thermograms. Even though it is non specific, thermography is a powerful detector of problems that affect a patient's physiology.

Some areas where thermography is being used successfully are vascular disorders , rheumatic diseases, oncology (especially breast cancer), tissue viability, neurology, dermatological disorders, neonatal, ophthalmology, and surgery. One of the main medical area where the importance of the thermography is rising is the recent years is the monitoring of thermographic regions during the physical exercise.

As is note the physical exercise just like inflammatory processes influences skin temperature, by modifying blood flowing and the temperature of the specific warming area [2,3]. Many authors have focused on clinical application of hand thermography during the physical exercise. Muth [4] and Kirsis [5] noted a reduction of the blood flow in the skin of the hand during the initial phase of physical exercise, which reverses as work progresses. Zontak [6] noted by means of an Infra-red system that blood flows and temperature variations are correlated. Physiology provides an explanation for this; in fact, in the initial phase of exercise the demand of blood flows causes a certain degree of skin constriction; then, when the body temperature rises, the thermal regulatory process becomes predominant and cause the dilatation of skin blood vessels, which makes both the blood flow and heat conduction of the skin increase [7]; however pathologies, such as the inflammatory processes can influenzate this physiological process. Literature analysis showed the need of the development of a wearable thermographycal device; this equipment should be used during medical continuous monitoring. Many technologies are suitable for skin thermography. The most commonly used technologies are infrared and liquid crystals , but they are not suitable for wearable continuous monitoring applications, because of their encumbrance and complexity. Bolton [8] has recently proposed a wearable system consisting of a compact data logger for ambulatory skin temperature measurement with which he achieved an eight-channel high-resolution dynamic-height-points thermometer system based on surface montage thermistors. Other interesting realisations based on the use of silicon components were made in the eighties [9,10,11], but with the advances in microprocessor technology and package reduction performances are achieved that were previously unthinkable of. On the other hand, thermocouple-based realisations need complex compensation circuits as described in [12]. Our goal was then to design a novel equipment based on silicon integrated components developed with the present-day technologies with a suitable resolution, and test it on a clinical hand thermographical application to compare the performances obtained with other methodologies.

Materials and Methods

System description

The objective of the project was to obtain a practical device, with minimal encumbrance, and adequate thermal resolution in the range of clinical applications. Figures 1A and 1B show the block diagram of the complete equipment. The hardware incorporates a sensor unit with 16x16 Silicon Celsius precise sensor thermometers (odoscope unit) and a service unit comprehending the multiplexing circuit , the processing and conditioning circuit, a powering oscillation

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connecting and stabilisation circuit and the Pentium IV pc. A dedicated software has been designed to display data.

The odoscope unit

The thermal sensor unit is arranged through 16 rows and 16 columns of a matrix box. Each cell of the matrix box corresponding to an area of 4mm x 4 mm is monitored by one silicon sensor Celsius thermometer based circuit. The face of the matrix box put in contact with the skin is made of a traspirant sponge and carries the 256 thermal sensors packages (model lm335,National, USA) [12] The Reference of the lm308 is fixed by means of the specific lm336 component (national semiconductor, USA) [12] . A precise voltage generator provides the signals ADJ-ij1 and ADJ-ij2 6 . It allows the instrument to be tuned for an excursion of 17 degrees. The output gradient is 10 mV/°C. The core of the circuit is the component lm335, chosen because of the optimal calibrated error response it shows in the range of interest [12]. This sensor was obtained after a simulation study conducted on different thermal sensors [25]

Service unit

<u>1 Multiplexing circuit</u>

The thermal variations in clinical applications are not rapid; the time of selection of each channel was not then a critical parameter. Two analog multiplexes layers were adequate to drive the selection of the TS channels. The first multiplexe layer consists of sixteen 396 components (MAXIM, USA) which are sixteen-to-one multiplexes, which select a row. The second layer consists of one 396 (MAXIM,USA) component which selects one of the sixteen columns of the row.

<u>2 Processing and conditioning circuit</u>

The conditioning chain comprehends a non-inverting amplifier consisting of the lm308 operational and a low-pass filter. The low-pass filter has been developed by means of a second order Sallen&Key cell In order to obtain full dynamics at the output the Cascade Gain G_2 was set at 83,34.
The chosen parameters were the following:

A) gain in band G2=A2=1+Rb/Ra

B) Cut off frequency = 1000 Hz

In order to obtain the Butterworth approximation:

C) Rb/Ra was set at 0.6.

The Gain G2 =1+0.6

D) G1= 52.125

A PIC 16F877 microprocessor is used for the data handshaking control and the multiplexing unit control.

<u>3 powering oscillation connecting and stabilisation circuit</u>

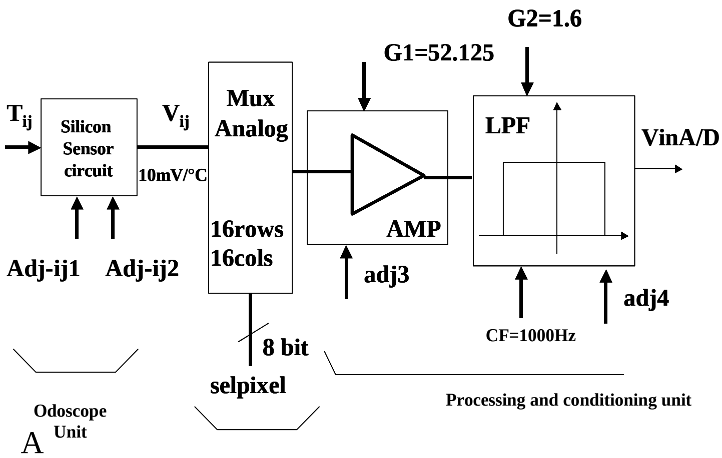
The unit comprehends a 4MHZ oscillator M.E.C.Y.Oz (MEC, USA), an L7805regulator (ST, USA) in the stabilization circuitry.

Software interface

The software interface has been developed by means of MatalbR12 software for the real time displaying and the thermographic colour mapping association to the 256 channels.

Calibration and bench test

The equipment for calibration and bench testing comprehends a Warming Testing Unit which was developed for this project; it consisted on a thermal bath sensed by means of a high-resolution precision mercury thermometer with an accuracy of 0.02 °C. By means of a dedicated procedure it was possible to obtain the calibration function for each channel in the range of interest by heating the bath in the range 27 °C..41 °C . A controlled oven was also used to test the equipment for long time monitoring.



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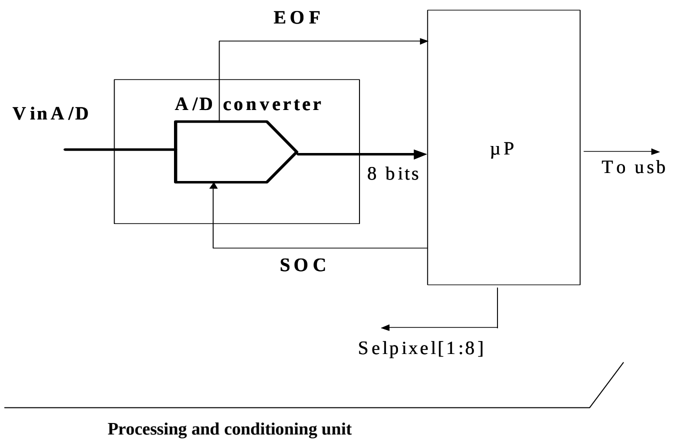

(B)

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Figure 1A and 1B The architecture of the system

Results

Figure 2 shows the complete equipment with the odoscope unit with the sensors and the service unit with the rest of the circuitry. The odoscope unit can be affixed in the region of interest; the service unit can be worn by means of a normal belt. The WTU was realised by means of an adiabatic case where inside were placed 10 conductive-gum disk and two electrodes with current injection controlled by a PIC16F877 (Microchip,USA) to warm the bath and a mercury thermometer with 0,02 °C of accuracy, the PIC was used to pilot the current injection to obtain the curves reported above.
The layout was developed by means of the Protel tool (Protel, USA); the layout area of the odoscope unit was $6,4*10^{-3}$ m^2; the layout of the service unit the was $4*10^{-2}m^2$. The weigh of the equipment with cases and cables comprised was 210g for the odoscope and 770g for the service unit. The component part list chosen to optimise the layout comprehends the following optimised packages: To92 for the thermal sensors, To92 for the thermistors, Dual in Line 16 pin package for the IC Amplifiers, Dual in Line 28 pin package for the analog multiplex and, Mrs25 package for the resistance, plus mica-silver radial condensers for high stability and performance.
The spatial resolution which can be achieved by means of the instrument is pr=1,6*10-5 m^2 for a filed of view of 256 pixel for an area of 256* pr.

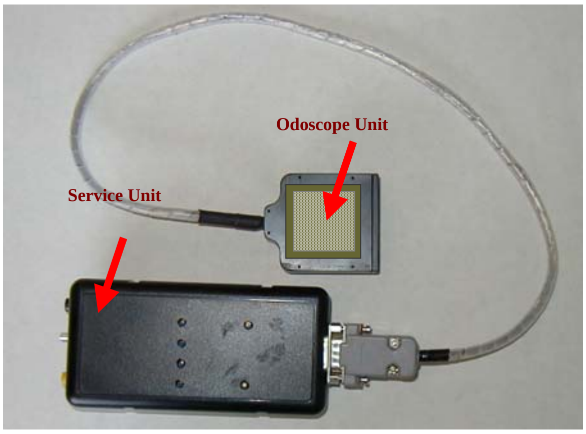

Figure 2 The architecture of the system

Calibration Results
- The characteristics of the 256 channels were:
- cross-talk absent
- non-linearity < +- 0,1% fs
- hysteresis < 0,1 % fs
- accuracy 0,3 % fs
- overall resolution better than 0.1 °C in the windows of interest, the substantial limit was determined by the quantization noise of the A/D conversion.

Student's T test on 100 trials proved the stability of the instrumentation with 1°/°° significance.

Stabilty of long time measure
By means of the controlled oven it was also possible to test the stability of the measure, which it was proved to by better than 0, 06 °C / 6h in the range 27..41 °C. It was also showed the absence of drifts and the feasibility of the use of the equipment for the long time monitoring. The Student's T test showed for this trial a significance of 1°/°°.

Discussion and Conclusions

The utility of the thermographical investigation have been demonstrated in many clinical applications [1-3]. Many new promising investigations of skin thermography [4-6] showed that the necessity of the development of an equipment for the continuous thermographical monitoring was rising to improve the comparative study of the temperature with other physiological parameters such as for example those connected with the physical exercise [14].
The equipment hereby described permits the thermographical continuous monitoring and reconstruction of the skin region to which it is affixed. Prior to this paper the problem of the dynamic thermographycal continuous monitoring by means of contact technologies was afforded by Bolton [6]. His solution permitted the contemporary thermal contact monitoring of height different points and was intended for the thermal monitoring of discrete body points. Our equipment on the contrary was designed for the monitoring of a defined Skin Area. It also permits the continuous thermographic monitoring with high performances and a complete colour mapping reconstruction. Thanks to the polarization and conditioning chain it was possible to obtain appropriate voltage ranges, without having to resort to complex compensations as with thermocouples [12] . Contrarily to the thermoresistors used in [8], the Integrated Components used in the project had good linearity and stability in the windows of interest, facilitating the calibration and the circuitry and constitute a valid alternative to the use of other type of components such as thermistors or termocouples [8,12] for these kind of applications.
The clinical application showed substantial agreement with the data obtained by Zontak by means of Infrared Thermography [6], with reference to the temperature drop in the particular clinical chosen exercise. Considering that the proposed equipment does not constrain the subject during physical exercise it can be used in all those clinical monitoring applications where the IR technology is not applicable. This equipment could be also useful for example in breast cancer thermography where the thermography showed its power in sensitivity [17], validity [18], capacity in discriminating density[20] and size[21], response to chemioterapic therapy [23] and where recent studies

showed the necessity of long time acquisitions tuned on the circadian rithms [15] The equipment also responds to the rising demands of patients' monitoring by means of portable/wearable instruments carried out by the wonderful development of miniaturisation technologies and by the general interest in the non invasive parameters monitoring well documented by P. Bonato in his recent issue of the IEEE Engineering in Medicine and Biology magazine [13]. At the moment we are investigating the realisation of the equipment by means of hybrid circuits to improve the portability of the equipment and the designing of post-processing procedures for data mining based on ANN methodologies which could improve the medical knowledge.

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