REAL TIME PROCESSING AND DATABASE OF MEDICAL THERMAL IMAGES

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Abstract

Thermo vision systems are very popular in applications like military and police systems, systems for custom traffic control, industrial and medical systems etc. The information existent in thermal images of human bodies or human faces is very important because it can increase the right decision for final patient diagnostic and also can be used in thermo vision information system for customs control and combating terrorism. This information is usually presented as visualisation of thermal images in pseudo colours. From these images the diagnosis decision is made subjective usually after the doctor visual observation of the region of interest in thermal image. Therefore, the goal of this article is to develop real time algorithms in the medical thermal image systems for automatic medical thermal images processing and diagnostics. This will decrease or eliminate the subjective doctor errors in the diagnostic process. Also the proposed real time automatic processing algorithms will allow quick collection in the appropriate databases of the typical cases in diagnostic practices of frequently occurrence of the thermal images classes, which can be added and used in the global telemedicine information systems for diagnostics or used in thermo vision information system for customs control and combating terrorism.

1. Introduction

Medical thermal image systems consist mainly from thermal image sensors [1] or Thermo Camera (Fig. 1) for capturing thermal images of human body containing regions of interest for medical diagnostic.

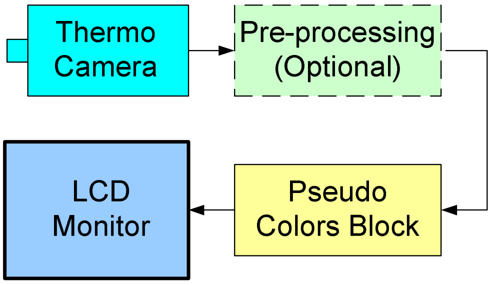

Fig. 1

The medical thermal or infrared medical images captured with Thermal Camera can pass optionally through the Pre-processing Block for some simple and usual transformation and then through the Pseudo Colours Block for representation of each pixel temperature value as an appropriate and predefined pseudo colour for displaying on a standard video LCD monitor. The thermal images on the screen of the LCD video monitor usually are inspected and estimated from the doctors to decide whether or not the region of interest is connected with a disease (Fig. 2).

Fig. 2

To avoid subjective decisions or errors it is more convenient to apply automated methods and algorithms for thermal images processing to increase of contrast, resolution, general thermal images quality or to separate the regions of interest and finally to direct the doctors attention to the places of interest in thermal images. This is the goal of this article to propose the real time algorithms in the medical thermal image systems for automatic medical thermal images processing and diagnostics.

First it is necessary to outline the basic principles of human temperature representation in thermal images and the reasons of deviations from the ordinary values of a healthy person.

2. The basis principles of human temperature representation in thermal images

The human temperature in each moment can be described and is depending from many factors. There are the different ways a human loss or gain the heat from the environment. The body's core temperature remains constant on the condition that there is head balance between the heat production and the heat loss [2]:

$$S = M \pm W \pm R \pm C \pm K - E - RES, \qquad (1)$$

where:

S is heat storage;
M – metabolism influence value of human temperature;
W – external work influence value of human temperature;
R – heat exchange by radiation influence value of human temperature;
C – heat exchange by convection influence value of human temperature;
K – heat exchange by conduction influence value of human temperature;
E – heat loss by evaporation influence value of human temperature;
RES – heat exchange by registration influence value of human temperature.

The above heat balance equation (1) is often used. However, when dealing with a person with clothing it is preferable to write the heat balance substituting $S = 0$ in equation (1):

$$M \pm W - E - RES = \pm K_{cl} = \pm R \pm C, \qquad (2)$$

where:

K_{cl} is heat conduction through the clothing influence value of human temperature.

The equation (2) implies, that the metabolism (M) including the external work (W) minus the heat loss by evaporation (E) and respiration (RES) is equal to he heat loss conduction through the clothing (K_{cl}) and equal to the heat loss by radiation (R) and convection (C) from the other surface of the clothing. The sign indicates that the parameter may be negative or positive i.e. heat loss or heat gain. The equation (2) does not take into account the heat exchange by conduction, for example, when loading sacks or the contact between feet and floor. This amount is normally insignificant influence on local heat exchange (warm fingers, cold toes). A person seated in an armchair, will exchange heat by conduction to the chair should be calculated as part of the clothing.

The influence of the metabolism M for the human temperature can be explained as energy released in the body by oxidation. This takes places at a rate which is equivalent to the amount of energy the body needs to function. The value of M may vary form a rest value of approximately $45 W/m^2$ skin surface $(0{,}8\,met)$ to more than $500 W/m^2 (\approx 9\,met)$ when running. The surface area of a normal person is approximately $1{,}8 m^2$. The energy released is some times partly converted to external mechanical power W but is mainly converted into internal body heat. The metabolism is often given in the unit "met", where $1 met$ is equal to the metabolism for a seated, resting person $(1 met = 58{,}15 W/m^2)$.

The influence of the external work W can be either positive or negative, if a person cycles on an ergo meter with a heavy load, he must use a lot of energy to keep a constant velocity $(r/\min)$. This energy is split in two parts: W is the amount which is necessary to overcome the resistance from the load. In this case W is positive. The other part is the internal heat productions, which is necessary for the body to perform external work equal to W. This part of the energy is used to pump more blood around the increase the respiration. Main is however, a very poor machine. The efficiency is less than 20 % even for well-trained athletes. Thus if the load on the ergo meter is increased such that the corresponding W is increased by $10 W/m^2$, then the metabolism will increased by $50 W/m^2$. The extra $40 W/m^2$ must then normally be lost by increased sweating to avoid increment of the internal temperature. If one walks down a steep hill and has to "brake" not to get too much speed, some of the potential energy will be transformed to heat in the muscles. The external work, W is in this case negative. The external work can be also lifting a tool, sack or case and they increase the potential energy for this object.

Heat Loss by Evaporation is partly from water vapour diffusion through the skin (E_d) and party by evaporation of sweat on the skin surface the skin (E_{SW}). When evaporation takes places the water uses heat from the skin. The amount of water diffusion through the skin and the corresponding evaporative heat loss (E_d) is a function of the difference between the saturated water vapour pressure at skin temperature (p_s) and the water vapour pressure in the ambient air (p_a):

$$E_d = 3{,}05.10^{-3}(p_s - p_a), W/m^2, \qquad (3)$$

where p_s and p_a are in Pa (Pascal).

The saturated water vapour pressure at the skin surface is a function of the skin temperature (t_s):

$$p_s = 256t_s - 3373, Pa. \qquad (4)$$

Inserting (4) in (3) we obtain

$$E_d = 3{,}05.10^{-3}(256t_s - 3373 - p_a), W/m^2 \qquad (5)$$

Water diffusion through the skin will normally result in a heat loss equal to approximately $10W/m^2$. A typical case is skin temperature $t_s = 33^o$ and a water vapour pressure $p_a = 1400Pa$ in ambient air (50% relative humidity at 23^oC air temperature). This ill result in a heat loss equal to $11{,}2W/m^2$. The heat loss by water diffusion through the skin takes place all the time and is not controlled by the thermo-regulatory system.

Evaporation of sweat from the skin surface (E_{SW}) is one of the most effective ways by which the body can keep the internal temperature from increasing even during hard work. The amount of this evaporation may change a lot with activity (from $0\,W/m^2$ at rest to maximum $400\,W/m^2$ with very hard work) in a hot, dry environment. It is limited how much a person is sweat and there are great individual differences. Persons who are used to living and working in hot environments or performing hard work can improve the function of the sweat glands and obtain a better control of the body temperature. An acclimatised person is normally not able to sweet more than $1l$ per hour, and a total amount approximately $3{,}5l$. If all this sweat is evaporated, it is equal to a heat loss of $675\,W$ ($375\,W/m^2$) and a total amount of $8505kJ$. During hard work in hot environments it is important to drink water (plus salt) to be able to sweat enough. The estimation of the heat loss due to the evaporation of sweat is rather complicated and not fully understood yet. By excessive sweating some of the produced sweat will drip and does not remove any heat from the body by evaporates at the skin surface that removes heat from the body.

3. The structure of the thermo vision system for thermal medical diagnostics and telemedicine

The detailed description and representation of the factors influencing the human bodies or faces temperature can be used in development of the structure of an automated thermo vision system with applying of real time processing algorithms for thermal diagnostics and application in telemedicine. The proposed structure is presented in Fig. 3.

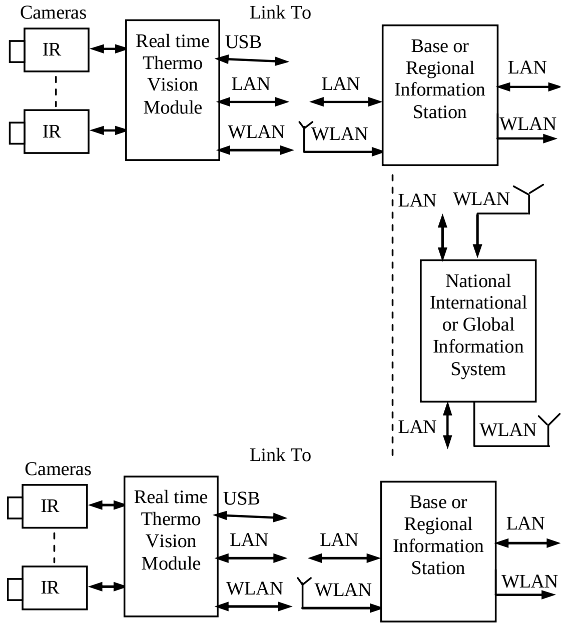

Fig. 3

The most important part of the proposed medical thermal vision system shown in Fig. 3 is the Real time Thermo Vision Module. The proposed internal structure of this module, in which are implemented the proposed and developed real time processing algorithms for thermal medical diagnostics, is shown on Fig. 4.

The main part of the infrared processing module is the embedded Digital Signal Processor (DSP), chosen to realize in real time most of the time consuming the developed medical infrared image processing algorithms. As a very popular possibility to extend the digital signal processor calculation capabilities it is proposed and shown in Figure 1 a Field Programmable Gate Array (FPGA) [3], which can also take up some of the necessary and usually control and communication functions from digital signal processor to the telemedicine information systems.

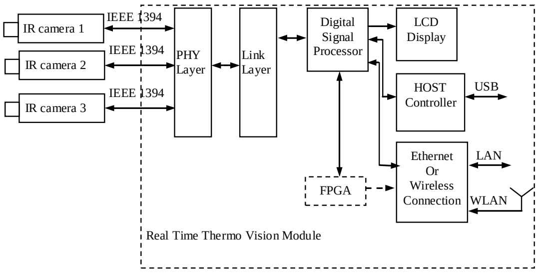

Fig. 4

The digital signal processor must have the possibility to drive a LCD Display for viewing input thermal images of human bodies or faces captured from each IR Camera or processed from digital signal processor medical thermal images. This can be done if digital signal processor is chosen from a set of special class signal processors known as Digital Media Processors [4]. These signals processors are also capable to interface with a specified host controller to the desktop or host computers. This guarantees the easy way to develop and test the algorithms for medical thermal images processing before their real time implementation in an embedded digital signal processor. Finally it is usually necessary to transmit the results from the medical thermal images processing or results from thermal diagnostics as important information for the medical telemedicine systems. The transmission can be accomplished by means of standard Local Area Networks (LAN) or Wireless Networks (WLAN).

The main advantages of the proposed internal structure of this module are:

- real time capturing of medial thermal images from standard thermo vision cameras;

- standard interfacing between digital signal processor and thermo vision camera in medical applications;

- visualization of input and processed medical thermal images;

- possibility to use desktop or host computer for development and testing application algorithms of automated thermal medical diagnostics using real time infrared image processing;

- collection of results of captured and processed medical thermal images and results from diagnostics in the in the appropriate databases of the typical cases in diagnostic practices of frequently occurrence of the thermal images classes;

- communication in wired or wireless LAN (Local Area Network) for transmission of results of captured and processed medical thermal images and results from diagnostics, which can be added and used in the global telemedicine information systems for diagnostics.

4. The algorithm of feature extraction using the proposed real time medical thermal images processing module in thermal medical diagnostics and telemedicine

To prove and demonstrate the real time processing abilities of thermo vision module it is proposed to apply and test this module in the applications of medical thermal images feature extraction. The testing is carried out with a Simulink model shown in Fig. 4. The extraction of features with real time medical thermal image processing is implemented in the block "General Real FIR" in Fig. 4.

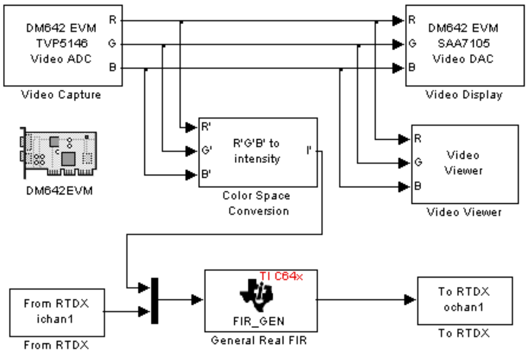

Fig. 4

This block is a part of embedded C64xxDSP Library included in Matlab [5]. The main processing function of this block is to accomplish real time filtering of incoming data (in this case medical thermal image data) in the embedded digital signal processor module. The detailed representation of the block with name "General Real FIR" in Fig. 4 is presented in detail form on the Fig. 5.

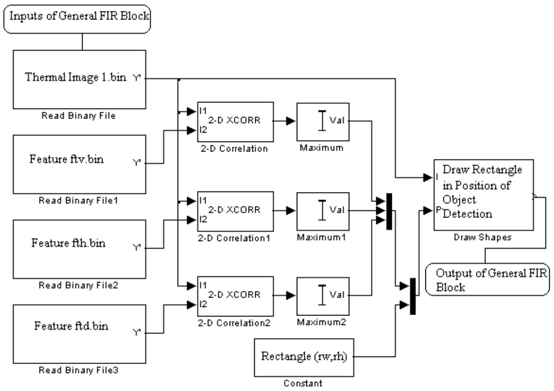

Fig. 5

The thermal image data are presented inside this block in form of binary image data format and are shown as first block "Read Binary File" in Fig. 5. In this article is proposed a modification of the algorithm for features extraction [6] in form medical thermal images. The features in form of rectangles are collected as templates and are also presented in Fig. 5 as "Read Binary File 1", "Read Binary File 2" and "Read Binary File 3", respectively for each of the chosen in [6] features: vertical (ftv.bin), horizontal (fth.bin) and diagonal (ftd.bin) in form of rectangles. In each of the "2-D Correlation" blocks is applied the following equation to calculate the two dimensional cross-correlation $\mathbf{C}(i,j)$ between the matrix of the tested thermal image and each of the matrix of the features in form of rectangles "ftv", "fth" and "ftv":

$$\mathbf{C}_k(i,j)=\sum_{m=0}^{N_y-1}\sum_{n=0}^{N_x-1}\mathbf{TI}_m(m,n).\mathbf{FT}_k(m+i,n+j) \qquad (6)$$

for $0\le i\langle N_y+N_{f_k}^y-1; 0\le j\langle N_x+N_{f_k}^x-1; k=1,2,3$,

where:

$N_x, N_y, N_{f_k}^x, N_{f_k}^y$ – horizontal and vertical dimensions of thermal image matrix $\mathbf{TI}_m$ and $\mathbf{FT}_k$, respectively;

$k=1,2,3$ – index of three features matrix $\mathbf{FT}_1,\mathbf{FT}_2$ and $\mathbf{FT}_3$ for features "ftv", "fth" and "ftd", respectively.

From these three outputs of the blocks "2D Correlation" the values in matrices $\mathbf{C}_k(i,j)$ are estimated in three Simulink blocks named "Maximum ...", to calculate the maximal values $ft_k^{\max}$ in each of three matrices $\mathbf{C}_k(i,j),(k=1,2,3)$:

$$ft_k^{\max}=\max[\mathbf{C}_k(i,j)] \qquad (7)$$

for $k=1,2,3$.

The calculated in blocks "Maximum ..." maximal values $ft_1^{\max}, ft_2^{\max}$ and $ft_3^{\max}$ correspond to determination existence of features for vertical "ftv", horizontal "fth" and diagonal "ftd" properties in tested "Thermal image 1".

5. The experimental results and conclusion

The results of experimental test of extracted features in the some of the chosen medical thermal images are obtained with the proposed in the Fig. 4 blocks of Real time Thermo Vision Module. There are carried out tests with a collection in a specialized database of more than 600 medical test images of human bodies and faces. One of these test images is shown as an example in Fig. 6.

Fig. 6

The results of real time rectangle features extraction and regions of interest outlining are shown in Fig. 7 and Fig. 8, respectively, marked with the appropriate rectangles in the tested medical thermal image.

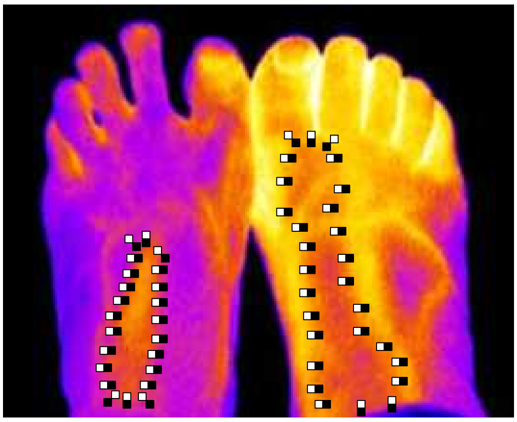

Fig. 7

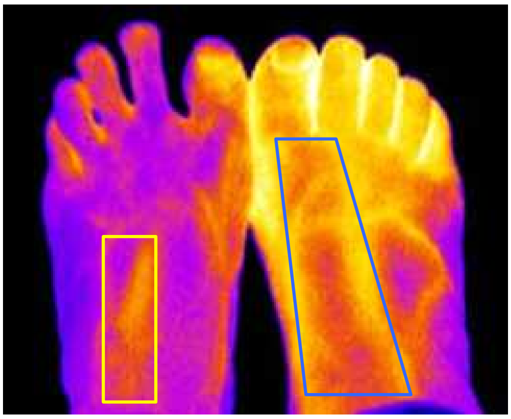

Fig. 8

6. Acknowledgments

This work was supported by National Ministry of Science and Education of Bulgaria under Contract DDVU 02/04/2011: "Thermo Vision Methods and Recourses in Information Systems for Customs Control and Combating Terrorism Aimed at Detecting and Tracking Objects and People**".**

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