Thermo vision system with embedded digital signal processor for real time objects detection

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Abstract: - Thermo visual systems are used with success in many cases of surveillance and observation. The goal of this article is the development of a real time embedded digital signal processor module in thermo vision information system for customs control and combating terrorism. It is proposed the structure of an embedded digital signal processor module suitable for real time thermal images processing. It is implemented in the embedded digital signal processor module the algorithm developed for this thermo visual system witch accomplished choosing, analyzing and estimation of a minimal set of features for objects detection in thermal images. The proposed module is tested for real time detection of objects hidden in baggage or dress of people.

Key-Words: thermo visual systems; digital signal processors; real time thermal images processing and objects detection

1 Introduction

Thermo or infrared vision systems are very popular now and are used in a widespread areas like military, police custom traffic control, industrial and other specific applications [1,2]. The main reasons for the fast and permanent increasing of the popularity of thermo vision system are not only the need for using these systems in variety of applications, but also the development of the compact with the excellent characteristics infrared video cameras [3]. There are also a lot of software tools [2,4] helping the development and testing application algorithms for thermal image processing, infrared spectroscopy etc. Despite many existing hardware (infrared cameras) and software development tools, there is a need mainly in practical applications of thermo vision systems for real time thermal images processing.

The goal of this article is to propose a suitable architecture of a module for real time infrared images processing and implementation of some algorithms for demonstrating the work of proposed module in real time situations of objects and people detecting. The proposed real time working thermo vision processing module is presented in this article as a main part of a thermo vision information system for customs control and combating terrorism.

2 Thermo Vision system with Embedded Digital signal Processor

A. The architecture of a Real time Thermo Vision Module

The general requirements for development of a real time working thermo vision module, taken info account here in this article, are:

- real time capturing of thermal images from standard thermo vision cameras;
- standard interfacing between digital signal processor and thermo vision camera;
- possibility to use desktop or host computer for development and testing application algorithms for infrared image processing;
- visualization of input and processed thermal images;
- communication in wired or wireless LAN (Local Area Network) for transmission of result of captured and processed thermal images, finding and tracking objects or people in area of thermo vision cameras observation.

The conditions mentioned above are satisfied in the proposed architecture of the real time thermo vision module, presented in Figure 1.
As it is shown in Figure 1 the real time capturing of thermal images is made from several (1÷3) infrared cameras (IR Cameras), which can be placed near (1÷3 metres) to the real time infrared processing module.

The connection between each of the IR Camera and real time infrared processing module is arranged with the standard interface IEEE 1394 [5], which allow real time transfer of the thermal images from IR Cameras to the infrared processing module.

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 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) [6,7], which can also take up some of the necessary and usually control and communication functions from digital signal processor.

The digital signal processor must have the possibility to drive a LCD Display for viewing input images captured from each IR Camera or processed from digital signal processor 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 [8,9,10]. 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 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 thermal images processing as important information for the objects or people detected and tracked in the area of IR Cameras observation. The transmission can be accomplished by means of standard Local Area Networks (LAN) or Wireless Networks (WLAN).

In Figure 2 it is shown an example of the structure of a thermo vision information system with proposed embedded digital signal processor module.

Each of the proposed modules for real time processing with embedded digital processor is shown in Figure 2 as a block with several IR Cameras connected to the module. The communication interfaces (Wired LAN or Wireless WLAN) gives the possibility of each module to transmit the results of processed thermal images to a set of base or regional stations (police, military, customs control, etc). These stations on the other hand can retransmit (Link To) a generalized information for the processed thermal images to a built national, international or global information system for police or customs control of dangerous objects or people detection and tracking.

The proposed architecture of thermo vision module, shown in Figure 1 and its place as embedded module for real time processing in a thermo vision system, shown in Figure 2 is based on the digital signal processor modules [8,10].

Figure 2. The structure of a thermo vision information system with proposed embedded digital signal processor module.
To prove and demonstrate the real time processing abilities of thermo vision module it is proposed to apply and test with this module the objects detection in thermal images using the algorithm proposed in [11]. The testing is carried out with a model shown in Figure 3 and created with Embedded target for Texas Instruments Digital Signal Processor Toolbox in Matlab Simulink.

The advantage of the proposed testing methodology is the link of the Simulink model with the Texas Instruments Code Composer Studio Integrated Development Environment [13].

There are two possibilities to real time input of thermal images, shown in the proposed model in Figure 3 of development embedded module.
- input from thermal video camera, shown in Figure 3 as Simulink block “Video Capture”;
- input from files of preliminary recorded thermal images, shown in Figure 3 as Simulink block “From RTDX”.

The first type of input thermal images is suitable for testing algorithm for objects detection with real thermal images, using the standard for thermal video cameras interface IEEE 1394, shown in Figure 1 of the proposed embedded module for real time thermal images processing. The speed characteristics of the used digital thermal video cameras and interface IEEE 1394 guarantee the real time possibility to input thermal images in proposed embedded module.

Thermal images video capture from thermal video camera are usually pseudo color images and each of the colors in image, represent a corresponding temperature in the range of the concrete thermo visual sensor chosen in a thermo visual video camera.

In the Figure 3 is added a “Color Space Conversion” block to transform pseudo color thermal images in more simple for real time processing form only as a pseudo grey scale thermal images, marked with I (Intensity) on output pin of the “Color Space Conversion” block.

The second way of real time input for thermal images is presented in Figure 3 with the Simulink block “From RTDX”, which mean of using a defined real time input channel “ichan 1” to send thermal image data from host (Personal Computer PC) to target (Embedded Digital Signal Processor).

It is supposed in this case that the defined input channel “ichan 1” is configured to give to its output thermal images data directly in from of pseudo grey scale images.

The proposed two ways to input the thermal images data for real time processing in embedded digital signal processor module can be switch over with the Simulink block “mux or multiplex”, shown in Figure 3 like a “bar” with two inputs for multiplexing each types of thermal images data from outputs of the “Color Space Conversion” block (Video Capture Images) and “From RTDX” block (ichan1 images), respectively.

The output of the “multiplex” is connected to a “General Real FIR” block, which is a Simulink block in the Embedded Target for Texas Instruments C6000 Digital Signal Processor Library. This library is a collection of frequently used general purpose signal processing algorithms, developed and tested from Texas Instruments and designed especially for their digital signal processors from C6000 series.

The rest block on Figure 3 are for displaying and post processing of the results after execution of the algorithm, proposed in [11] for objects detection in thermal images using features in form of rectangles. The block “Video Display” in Figure 3 gives the possibility to display and visual observation of the resultant thermal images after processing in block “General Real FIR”. The block “Video Display” is local LCD monitor as a part of the embedded digital signal processor module.

The other way for display the resultant thermal images after processing is shown in Figure 3 with the block “Video Viewer” existing in Simulink Toolbox. This is the way to watch the resultant thermal images on the video display of host computer connected with the embedded digital signal processor module.

Post processing, saving or recording the resultant thermal images can be accomplished through the block “To RTDX”, shown in Figure 3. This block allow to send the resultant thermal images data from the memory of the embedded digital signal processor module to the host computer via the defined in Simulink digital channel “ochan1”.

The resultant thermal images data transferred through the digital channel “ochan1” to the host computer can be used first to calculate the coordinates or the position of the detected object in thermal images. The ability of
digital channel to transfer data for the thermal images in real time mode extend the capability of the proposed embedded digital processor module from Figure 1 for real time tracking of the detected objects in the proposed architecture of thermo vision system for customs control and combating terrorism.

The features for real time objects detection proposed and analyzed in [11] are used here in this article and are implemented in the block “General Real FIR” in Figure 3.

The block “General Real FIR” is a part of embedded C64xxDSP Library included in Matlab. The main processing function of this block is to accomplish real time filtering of incoming data (in this case thermal image data) in the embedded digital signal processor module. In this article is proposed a modification of the structure of this block in accordance of the features in form of rectangles proposed in [11] for object detection in thermal images.

The proposed modification of the block with name “General Real FIR” in Figure 3 is presented in detail form on the Figure 4.

![Figure 4. The proposed modification and detail representation of the block with name “General Real FIR” in Figure 3](image)

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 Figure 4.

The features in form of rectangles are collected as templates and are also presented in Figure 4 as “Read Binary File 1”, “Read Binary File 2” and “Read Binary File 3”, respectively for each of the chosen in [11] features: vertical (ftv.bin), horizontal (fth.bin) and diagonal (ftd.bin) in form of rectangles.

In Figure 4 is shown the name of one image from the collecting in thermal images database. This thermal image “Thermal Image 1.bin” is chosen for testing from the created thermal image database and can be changed from the properties page of the Simulink block “Read Binary File”. In the same manner are presented and chosen also the names of the three features “ftv”, “fth” and “ftd” as binary files names Feature ftv.bin, Feature fth.bin and Feature ftd.bin, respectively. All these four Simulink blocks with appropriate names “Read Binary File” are treat as “Inputs of General FIR Block”, shown in Figure 3.

The output of the block “Thermal Image 1.bin” is connected to the inputs II of three Simulink blocks “2-D Correlation”, which perform matching in form of two dimensional correlation between chosen for testing Thermal Image 1 and each of the features “fth” and “ftd”, respectively. In these “2-D Correlation” blocks is applied the following equation to calculate the two dimensional cross-correlation $C_{ij}(k,j)$ between the matrix of the tested thermal image and each of the matrix of the features in form of rectangles “ftv”, “fth” and “ftd”.

$$C_{ij}(k,j) = \sum_{m=0}^{N_x-1} \sum_{n=0}^{N_y-1} T_{i,m} F_{j,n}^k (m+i, n+j)$$

for $0 \leq i(N_x + N_y^0 - 1); 0 \leq j(N_x + N_y^0 - 1); k = 1,2,3$ ,

where $C_{ij}(k,j)$ is two dimensional cross-correlation for each of three features $(k = 1,2,3)$;

$N_x$ and $N_y$ - horizontal and vertical dimensions of thermal image matrix $T_{i,m}$, respectively;

$N_x^k$ and $N_y^k$ - horizontal and vertical dimensions of the feature matrix $F_{j,n}^k$, respectively;

$k = 1,2,3$ - index of three features matrix $F_{j,n}^1, F_{j,n}^2$ and $F_{j,n}^3$ for features “ftv”, “fth” and “ftd”, respectively.

The outputs of three blocks “2D Correlation” contain the results of two dimensional cross-correlation in form of matrices $C_{ij}(k,j)$ for $k = 1,2,3$.

From these three outputs of the blocks “2D Correlation” the values in matrices $C_{ij}(k,j)$ are estimated in three Simulink blocks named “Maximum …”, to calculate the maximal values $f^1_{i,k}$ in each of three matrices $C_{ij}(k,j)$ for $k = 1,2,3$:

$$f^1_{i,k} = \max[C_{ij}(k,j)]$$

for $k = 1,2,3$ .

The calculated in blocks “Maximum …” maximal values $f^1_{i,k}$, $f^2_{i,k}$ and $f^3_{i,k}$ correspond to determination existence of features for vertical “ftv”, horizontal “fth” and diagonal “ftd” properties in tested “Thermal image 1”.

Three outputs values $f^1_{i,k}$, $f^2_{i,k}$ and $f^3_{i,k}$ from the corresponding outputs “Val” of the respective blocks “Maximum …” are merged using a Simulink block for multiplexing (the vertical black bar with three inputs in
Figure 4). The joined information for the positions of the maximal values \( \beta_1^{\text{max}} \), \( \beta_2^{\text{max}} \) and \( \beta_3^{\text{max}} \) determines and guarantee with some supposition and probability that from these joined feature positions is possible to locate the position of the objects in tested thermal image.

To mark the places of these possible object positions is added in Figure 4 the block “Constant” to define the initial characteristics of Rectangle (\( rw \), \( rh \)) with corresponding dimensions \( rw \) and \( rh \) for width and height, respectively. The initial values or \( rw \) and \( rh \) are added in a two input multiplex block in Figure 4 with the joined feature \( \beta_1^{\text{max}} \), \( \beta_2^{\text{max}} \) and \( \beta_3^{\text{max}} \) position information. The output of the multiplex block is connected to the input P of the block “Draw Shapes” in Figure 4. To the input I of this block is entered the visual information for the tested Thermal Image 1. The final results of the operation of this block is to draw the rectangles with the appropriate dimensions (width \( rw \) and height \( rh \)) in the possible places to mark detection of existent objects.

To reach this final operation and to achieve a good exactness of the important objects detection in tested thermal images are prepared the suitable operations for estimation of joined feature \( \beta_1^{\text{max}} \), \( \beta_2^{\text{max}} \) and \( \beta_3^{\text{max}} \) to define an object with some preliminary set forms and dimensions.

This is a very important and necessary processing step to eliminate from the list of possible detected objects the objects with small or large dimensions (exceeded the preliminary set dimensions) or the objects with an unusual or unexpected form. These restrictions depend from the application of the thermo visual system and here in this article are defined for the goal of detection the objects hidden in dress or baggage of people.

The results of detected objects separated and marked with the appropriate rectangles in the tested thermal image are directed to the “Output of General FIR Block” shown in Figure 4. Also this output is shown in Figure 3 connected to the input of the Simulink block “To RTDX”.

### 4 Test and results

The proposed in Figure 3 and Figure 4 Simulink models of algorithm for objects detection in thermal images described in [11] are first simulated to determine their correct work and then are transferred in the developed embedded digital signal processor module with the Davinchi Evaluation system of Texas Instrument [8]. As the thermal images are used the thermal images from database (more than 600) created in [11] for testing the proposed algorithm using feature in form of rectangles and feature minimization. The thermal images database contain examples of thermal images with objects and people, objects hidden in baggage or dress, like this shown in Figure 5.

![Figure 5. An example from the thermal images database of a thermal image with the object hidden in the dress of a person](image)

On Figure 6 is shown the result as an example the correct real time work of proposed in Figure 3 and Figure 4 Simulink models of algorithm for object detection labeled with a rectangle in a test thermal image and using the chosen minimal set of features in form of rectangles [11].

![Figure 6. An example of correct real time work of proposed in Figure 3 and Figure 4 Simulink models of algorithm for object detection labeled with a rectangle in a test thermal image and using the chosen minimal set of features in form of rectangles [11]](image)

The real time processing is tested with a real time thermal video stream with frame rate of 15 frames per second. It is concluded after using a lot of different thermal video streams in the experiments that for this speed (15 frames per second) of entering the thermal image frames in developed embedded digital signal processor module is possible to perform with success in real time processing tasks of the proposed algorithm of object detection in thermal images. This is an assurance.
to apply the proposed embedded module in a real working thermo vision information system for customs control and combating terrorism.

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