Development of Embedded Motion Detection in Thermo Visual System with Audio Visual Interface to Information Networks

S. Pleshkova
Department of Telecommunications, Technical University Kliment Ohridski, 8 Sofia
snegpl@tu-sofia.bg

Abstract: Thermo visual methods are widespread in security systems, surveillance or objects and people observation. One of the methods most commonly used, in such cases is the method for detecting motion for objects and people in the thermal image. This method is now developed in a number of modifications for the visible optical image, but may also be adapted for applications in the field of thermo visual systems. This article proposed a method for motion detection applied in thermo vision systems, which is based on the developing methods in embedded systems. As a practical realization of this embedded method is chosen the Xilinx Zynq™-7000 All Programmable (AP) SoC Video and Imaging Kit (ZVIK) builds on the Zynq-7000 AP SoC ZC702 evaluation kit (ZC702) by including additional hardware, software, and IP components for the development of custom video applications. In this case this video and imaging kit (ZVIK) is adopted to work with thermal images instead of visible images. Thermal images are captured from a thermal camera EasIR-9. The development of thermal video system and application software, in this case embedded motion detection algorithm, is prepared using firmware, and hardware designs tools. They included video reference designs, WUXGA color visible or thermal image sensor, and video I/O FPGA mezzanine card (FMC) with HDMI™ input and output as audio visual interface to external information systems or networks.

Keywords: Thermo Vision, Motion Detection, Embedded Systems, Audio Visual Interfaces

1. Introduction

The methods for motion detection of objects and people in the thermal image can be based on the existing well known similar methods for visible optical images [1,2]. The importance of motion detection of objects in thermal images is for thermal security systems, surveillance or objects and people observation in thermal images [3,5]. This article proposed a method for motion detection applied in thermo vision systems and this method is based on embedded systems as a practical realization. It is chosen to embedding the proposed motion detection algorithm for thermal images in the Xilinx Zynq™-7000 Video and Imaging Kit (ZVIK) [4]. This kit is for image processing of visible pictures captured with an ordinary video camera, but here is proposed to modify the Xilinx Zynq™-7000 Video and Imaging Kit (ZVIK) for capturing thermal images using a thermal camera EasIR-9 [6]. In this case embedded motion detection algorithm, is prepared using firmware, and hardware designs tools. They included video reference designs, WUXGA color visible or thermal image sensor, and video I/O FPGA mezzanine card (FMC) with HDMI™ input and output as audio visual interface to external information systems or networks.

2. Thermo vision images motion detection algorithm

The motion in the thermal images can be detected in a way similar to motion detection in visible images. One of these popular methods and algorithms for motion detection is based on generation of a binary image consisting from pixel, which take either the value "0" ('no motion') or "1" ('motion'). In order to determine the values $q(k = i)$ for each pixel $i$ in a thermal image is necessary to define a corresponding pixel in a defined difference thermal image $d(k)$ between two successive thermal frames, and compare the sum of absolute differences $\Delta_i$ within a sliding window $w_i$ with $N$ pixels and center $i$ to a threshold $T$:
\[ \Delta_i = \frac{2\sqrt{\frac{2}{\pi}}}{} \sum_{k=0}^{\infty} d(k) \quad 0 < T > 1, \quad (1) \]

where

\[ \sigma_\mu \text{ is the noise standard deviation of the thermal images level differences in stationary areas, which is assumed to be constant over space. The threshold } T \text{ can then be determined from:} \]

\[ \alpha = \Pr \left( \Delta_i > T | H_0 \right). \quad (2) \]

For a fixed false alarm rate \( \alpha \), \( T \) can be obtained from tables of the \( \chi^2 \)-distribution. In order to get such an adaptive threshold, the image grid is scanned from its upper left to its lower right corner. For each pixel are examined its 3 x 3 neighborhood and count the number of “changed” pixel found there. The higher the number \( n_i \) of “changed” pixels found in this neighborhood, the lower the threshold is:

\[ t(n_i) = T + (4 - n_i) B, \quad (3) \]

with \( 0 \leq n_i \leq 8 \). The parameter \( B \) is a positive-valued potential, which determines the range of \( t(n_i) \). If \( n_i = 0 \), the threshold \( t \) reaches its maximum value of \( T + 4B \). The minimum value of \( T - 4B \) results if \( n_i = 8 \), i.e. all neighbors of pixel \( i \) are labeled as “changed”. If there are as many “changed” as “unchanged” labels \( n_i = 4 \) it is obtained, that \( T = T \).

Equation (3) can be transformed to obtain the new adaptive threshold:

\[ t(n_i) = T + (4 - n_i) B + C \left( \frac{1}{2} - n_c \right), \quad (4) \]

with \( n_c \), either taking the value \( n_c = 1 \) (corresponding pixel of the previous thermal image frame labeled as “changed”) or the value \( n_c = 0 \) (corresponding pixel of the previous thermal image frame labeled as “unchanged”). Like \( B \), \( C \) is a positive potential. The intensity of a thermal image is generated by an incoming pseudo illumination (temperature), which is emitted or reflected by the surfaces of the objects in the observed thermo visual scene. As a first approximation, for emitted or reflected object surfaces the intensity of the \( \tau \)-th frame in an thermal image sequence is given by

\[ y_{\tau}(k) = i_{\tau}(k) r_{\tau}(k), \quad (5) \]

with \( k \) being the pixel-index, \( i \) the pseudo illumination (temperature), and \( r \) the reflectance component of thermal objects. It can be proved, that \( r \) contains mainly thermal object information. It is possible to separate \( i \) from \( r \) and use only this part of motion detection in thermal images. This separation is made by first applying the logarithm and then a linear high-pass filter. The logarithm transforms the multiplicative relation between \( y \), \( i \) and \( r \) into an additive one:

\[ \log(y_{\tau}(k)) = \log(i_{\tau}(k)) + \log(r_{\tau}(k)). \quad (6) \]

Equation (6) holds even in case of thermal camera nonlinearities like gamma correction, as in the log-domain the gamma exponent is transformed to a simple gain factor. From equation (6) is derived an appropriate homomorphic filter shown in Fig. 1. The homomorphic filter allows to obtaining motion detection independent of variations of pseudo illumination (temperature) in thermal images. The full algorithm of motion detection in thermal images is depicted in Fig. 2.

Fig.1. Homomorphic filter derived from equation (6)

The reflectance parts \( r \) and \( r+1 \) of the corresponding input thermal images frames \( y \) and \( y+1 \) are calculated and the motion detection is carried out.

Fig.2. Algorithm of motion detection in thermal images

3. The architecture of thermo visual system with Xilinx Zynq™-7000 Video and Imaging Kit (ZVIK) for embedding algorithm of motion detection in thermal images
The described above motion algorithm for thermal image is chosen to be embedded in the Xilinx Zynq™-7000 Video and Imaging Kit (ZVIK), shown in Fig. 3.

The Imaging Kit (ZVIK), shown in Fig. 3 is builds mainly on the Zynq-7000 AP SoC ZC702 evaluation kit (ZC702), which is the main part (closed part "Processing System" in Fig.4) of the Imaging Kit (ZVIK). Beside the calculation capabilities of the dual-core ARM® Cortex™-A9 MPCore™ the evaluation kit (ZC702) have the build-in Hardware Peripherals, which allow to connect and interfacing the external devices like PC and SD Card useful for the appropriates thermal images processing algorithms and also for the proposed in this article algorithm for motion detection in thermal images.

The specific part for the thermal image capturing, registration, visualization and transmitting capabilities of the Imaging Kit (ZVIK) is presented in Fig. 4 (Programmable Logic) by including additional hardware, software, and IP components for the development of custom thermal video applications. For the proposed in this article method for motion detection applied in thermo vision systems is very important to have the suitable input and output as audio and thermo visual interfaces. This is possible, because in the Imaging Kit (ZVIK) are included input video interface WUXGA for color visible or thermal image sensor, and video I/O FPGA mezzanine card (FMC) with HDMI™ input and output.
which can be used also as an appropriate audio visual interface to external information systems or networks.

4. Simulation and experimental results of thermal images motion detection algorithm embedded in Xilinx Zynq™-7000 Video and Imaging Kit (ZVIK)

The proposed architecture of Imaging Kit (ZVIK) with thermal camera for embedding motion detection algorithm is simulated and tested using the capabilities of Matlab Simulink system. The Simulink model of thermal images motion detection algorithm is shown in Fig. 6. The moving thermal images can be input in the Simulink model using the block “From Multimedia File” or directly from thermal camera using the block “From Video Device”. In Fig. 6 is presented the case to input of a moving thermal image from file IR000009.avi, recording from a real working thermal camera EasIR-9 and representing a moving man in the room (Fig. 7).

Fig. 6. The Simulink model of thermal images motion detection algorithm

The next block in Fig. 6 is named “Sum of Absolutes Differences” and it realized the described above thermal images motion detection algorithm presented as block schemas in Fig. 1 and Fig. 2. This block have two outputs: one is named “SAD” and other “AD”, which means “Sum of Absolutes Differences” and “Absolutes Differences”, respectively. A detailed internal representation of the block “Sum of Absolutes Differences” is shown in Fig. 8. The output “SAD” or “Sum of Absolutes Differences” is a quantitative measure of the existence of motion between two newborns frames in thermal images. The current value of the sum of absolutes differences is compared with an appropriate well chosen threshold (“Motion Threshold” in Fig. 6.).

Fig. 7. A frame of from file IR000009.avi, recording from a real working thermal camera EasIR-9.

The operation of comparison is carried out in the block signed in Fig. 6 with the symbol “>”, which means that this block output a logical signal “1” named “Detect” in the simulation model on Fig. 6.

Fig. 8. A detailed internal structure of Simulink block “Sum of Absolute Differences”

In a real time moving thermal image like this from the recorded file IR000009.avi the sum of absolutes differences is a as a stream of current values. These values can be presented in visual form using two blocks shown in the upper part of the simulation model on Fig.6. A fragment of the stream of current values of the calculated sums of absolute differences when running the simulation model is presented in Fig. 9 as a graphical output from block “Quadrant Motion Estimates” in simulation model (Fig. 6.). There are seen clear on Fig. 9 the registrations of real existing time intervals of motion and other without motion in the thermal images stream. The value of the chosen in Fig.6 threshold “Motion Threshold” is shown in Fig 8 as a horizontal line with the appropriate level.
Fig. 9. A fragment of the stream of current values of the calculated sums of absolute differences when running the simulation model.

Another way to represent the results of motion detection algorithm performed with the main operations in the block “Sum of Absolute Differences” is to use the outputs “SAD” and “AD” of this block for real-time visualization of existing motion in moving thermal images. This possibility exists in the proposed simulation model by using the developed block named as “See it” in Fig. 6. A detailed internal structure of this block “See it” is presented on Fig. 10.

Fig. 10. Detailed internal structure of this block “See it”

It is seen from Fig. 10 that the main part of the internal structure of the block “See it” is the standard Simulink visualization block “Video Viewer” which allows color image visualization. In the case of the thermal images motion visualization the separate RGB inputs of the relevant thermal image pseudo color matrices are preliminary formed using the other internal block shown in Fig. 10 “Block Processing” and “Grid lines”. The input logical signal “1” named “Detect” from the output of the block “Sum of Absolutes Differences” is used as first input (I1) of the “Block Processing” in Fig. 10 as gate to the thermal image frames which are entered on the second input (I2) of the “Block Processing”. The output of this block in Fig. 10 is used in the next block together with the input of thermal image. The function of this block is to assign values to specified elements of a multidimensional (in this case thermal image) output signal. The index to each element is identified from the input logical signal “1” named “Detect” of the first input (I1) of the “Block Processing”. In this way, it is formed a pseudo color image matrix which is put on the R (Red) input of the Simulink visualization block “Video Viewer” to indicate the space position in visualized thermal images if in the thermal images frames stream there are motion parts. On the second input of the Simulink visualization block “Video Viewer” G (Green) is entered the pseudo color image matrices G (Green) from the real thermal image stream. It is the same for the third input of the Simulink visualization block “Video Viewer” B (Blue), but it is preliminary processed in the block “Grid lines” as it is shown in Fig. 10 where it is added a grid of blue lines. These lines separate the output pseudo color thermal image stream to the rectangles in which it is more convenient to concentrate the attention for observation of existence or lack of motion in thermal image stream of frames. Such a frame with existence of motion in thermal image sequence of frames is presented in Fig. 11.

Fig. 11. The existence of motion in a frame from input thermal image file IR00009.avi shown after visualization from the block named “See it” in simulation model (Fig.6)

In the simulation model shown in Fig. 6 is included a switch for choosing the input image for the visualization block named “See it”. This switch allows choosing visualization from both the input thermal image from the input file IR00009.avi or from the image represented the absolute differences (AD) from the corresponded
output of the Simulink “Sum of Absolutes Differences” in Fig.6. In Fig. 11 is shown the situation, when the switch in simulation model on the Fig. 6 connect the input thermal image from the input file IR00009.avi to the visualization block named “See it”. Respectively in Fig. 12 is shown the situation, when the switch in simulation model on the Fig. 6 connect the thermal image represented the absolute differences (AD) from the corresponded output of the Simulink “Sum of Absolutes Differences” to the visualization block named “See it”.

Fig.12. The existence of motion in a frame from the thermal image represented the absolute differences (AD) from the corresponded output of the Simulink “Sum of Absolutes Differences” shown after visualization from the block named “See it” in simulation model (Fig.6)

The simulation model (Fig. 6) is modified (Fig. 13) with an audio interface which include a "Sine Wave" block, a block signed in Fig. 13 with the symbol “>” and a speaker ("To Audio Device") block.

Fig.13. The modified simulation model with an audio interface

8. Conclusion

The proposed embedded in the Xilinx Video and Imaging Kit (ZVIK) motion detection algorithm for thermal images is simulated to verify their work in real situations. It is shown that the differences between the existence of motion in thermal images represented on Fig. 11 and Fig. 12 are that in Fig. 12 are shown more precisely (as black rectangles) only the parts of the thermal image of absolute differences (AD), where there is a motion exceed the value of the chosen threshold. The model (Fig. 13) satisfy the requirements sets as the goal of this article to include an audio visual interface as a connection to the external information systems or networks of the proposed embedded in the Xilinx Zynq™-7000 Video and Imaging Kit (ZVIK) motion detection algorithm for thermal images.

Acknowledgment

This work was supported by National Ministry of Science and Education of Bulgaria under Contract DDVU 02/4-7: “Thermo Vision Methods and Recourses in Information Systems for Customs Control and Combating Terrorism Aimed at Detecting and Tracking Objects and People”.

References