Algorithm of feature estimation for real time objects detection in thermal images

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

Abstract: Objects detection in thermal or infrared images is an actual and necessary problem in wide range of thermo visual systems applications. The goal of this article is to select a suitable set of features for objects detection in thermal images. Using the objective methods and subjective expert estimation it is proposed a minimal numbers of features satisfying the conditions of real time objects detection with a preliminary defined precision for a chosen class of object hidden in dress or baggage of people. The chosen set of features is applied in the development of a real time embedded digital signal processor module in thermo vision information system for customs control and combating terrorism.

Key-Words: thermal images; infrared images; real time objects detection; features estimation

1 Introduction

The algorithms for object detection in thermal images are based on the general methods for image segmentation [1] and objects separation [2]. These general methods can be adapted or modified in applications for thermal image processing. Here in this article are used some of the basic principles in image processing for features extraction and estimation to development the algorithm of features selection, which are suitable for real time implementation in the proposed embedded digital signal processor module for objects and people detection in thermal images [3].

The principals of thermal images generation are defined in law by Stefan and Bolzmann:

\[ W = e \sigma T^4, \]

where

- \( W \) is radiant emittance (W/cm\(^2\));
- \( e \) – emissive;
- \( \sigma \) – Stefan-Bolzmann constant (5,6705x10\(^{-12}\) W/cm\(^2\) K\(^4\));
- \( T \) - temperature (K).

For objects or people detection it is necessary to know very precise the value of emissive \( e \). For example when thermal image contain the human face, the emissivity is \( e = 0.98-0.99 \) [4]. For other frequently detecting and separating objects from thermal images there are publications [5] with detailed descriptions and values of emissive \( e \), respectively.

The infrared camera [6] transform the thermal energy of objects, human face or body in form of 2D digitalized thermal images with horizontal and vertical dimensions \( N_x \) and \( N_y \), respectively. The temperature values of each objects or human point are represented as n-bits (usually 8 bits) numbers, which means \( 2^n \) (\( 2^8=256 \)) pseudo grey image levels.

2 Selection of a set of features for objects detection in thermal images

A simple and suitable for real time implementation method using for face detection in video surveillance systems [7] is modified in this article for development of an algorithm for extracting from the input thermal images \( tim_{in} \) a set of simple features in form of rectangles \( rec(x, y) \):

\[ rec(x, y) = \sum_{i=x_l}^{x_r} \sum_{j=y_t}^{y_b} tim_{in}(xi, yi), \]

where

- \( x, y \) are horizontal and vertical coordinates of the current thermal image pixel;
- \( x_l, y_t \) – coordinates of chosen most on the left and top pixel of a rectangle, relatively to the current image pixel with coordinates \( x, y \).

From equation (2) is easy to determine the following recurrent or iterative procedure:
\begin{align*}
rec(x, y) &= rec(x-1, y) + cs(x, y), \quad (3) \\
\text{where} \\
rec(x-1, y) &= \text{the prior calculated rectangle in} \\
pixel \text{with coordinates (x-1, y) of the thermal image tim,} \\
&\text{which is in the left horizontal position to the current} \\
thermal image pixel with coordinates (x, y); \\
\text{cs}(x, y) &= \text{calculated sum of thermal image tim} \\
pixels left and above of the pixels with coordinates (x, y); \\
\text{cs}(x, y) &= \text{cs}(x, y-1) + \text{tim}(x, y). \quad (4)
\end{align*}

The initial state of the recurrent procedure realized with equations (3) and (4) can be chosen as:

\begin{align*}
rec(0, y) &= 0, \quad cs(0, y) = 0 \quad (5) \\
\text{if} \quad x = 0 \text{ in rec(,..., ) and} \quad y = 0 \text{ in cs(,..., ) are horizontal} \\
\text{and vertical co-ordinates of a non-existing image pixel,} \\
\text{prior to the first real-existing thermal image pixel with} \\
\text{coordinates x=1 and y=1.}
\end{align*}

The simple determination of features in form of rectangles (2) and the possibility of their iterative calculation is a good reason for choosing these features for real time objects detecting and tracking in the proposed module for thermo vision system with embedded digital signal processor [3].

For a given class of objects detection and tracking in thermo vision system is necessary to choose the types and numbers in a set of features in form of rectangles. In general case the types and number of features can be chosen first from definition of a features window dimension:

\begin{align*}
FWD &= n_x n_y, \quad (6) \\
\text{where} \\
n_x \text{ and } n_y &= \text{horizontal and vertical dimensions of features window. It is usually to satisfy the condition:} \\
n_x < N_x \quad \text{and} \quad n_y < N_y, \quad (7) \\
\text{where} \\
N_x \text{ and } N_y &= \text{thermal images horizontal and vertical} \\
dimensions, \text{respectively.}
\end{align*}

Equation (6) and condition (7) gives only the general view for the choice or alternatives for the types of the features in form of rectangles, the number of which is quite large.

For each concrete case it is necessary to use some preliminary analysis to make an effective decreasing of the number of features and to choose only the types, which are more informatics for the goal of a specific application of object detecting.

For the case of objects detection and tracking in thermal images there are many ways to choose the types and the number of features in form of rectangles. Here it is proposed to consider only the case for security application of detecting objects hidden in dress or baggage and people, visible only from thermal images. The simplest set of features suitable for this case is chosen as simple combinations of horizontal, vertical, line and diagonal rectangle parts with different brightness or colors for gray scale or color thermal images, respectively. These prototypes or templates of chosen features in form of rectangles are shown in Figure 1 for a feature window with dimensions \( n_x \) and \( n_y \).

The proposed set of smallest number the features shown in Figure 1 can be extended with other most specific combinations (Figure 2) of dark and light rectangles or its rotated variants in the feature window, if it is necessary to improve the precision of the objects or people detection in the thermal images. But the addition of the extra features, to the basic feature is connected with corresponding calculation time increasing. Therefore, it is advisable to take account this additional time, especially in the cases of real time objects or people detection and tracking in thermal images.

![Figure 1. Prototypes or templates of chosen features in form of rectangles for a feature window with dimensions \( n_x \) and \( n_y \).](image-url)
Figure 2. The extended set of features in form of rectangles with other most specific combinations of dark and light rectangles or its rotated variants in the feature window.

The features in form of rectangles shown in Figure 1 and Figure 2 can be tested for their informative properties, when they are used to object and people detection and tracking in thermal images. There are two ways for caring out the informative properties test for the chosen features: objective and subjective. The objective tests for the features are based on estimation of their statistical independence, calculated and analyzed with some popular methods of decision theory [8].

3 Estimation of informative properties of the set of features for objects detection in thermal images

The estimation of the independence of features in form of rectangles can be done with method of principal component analysis [9].

The set of all initial chosen features in form of rectangles can be represented as a vector

\[
\mathbf{f}_{\text{fr}} = \left( f_{r_1}, f_{r_2}, \ldots, f_{r_n} \right),
\]

where

\( n \) is the initial number of features.

The estimated set of features \( \mathbf{f}_{\text{fr}} \) from the set of initial features is defined with basic principal component analysis equation:

\[
\mathbf{f}_{\text{xfr}} = \mathbf{A} \left( \mathbf{f}_{\text{fr}} - \mathbf{r}_{\text{fr}} \right),
\]

where \( \mathbf{r}_{\text{fr}} \) is the mean value of initial features \( \mathbf{f}_{\text{fr}} \);

\( \mathbf{A} \) - the transformation matrix in the principal component analysis.

The calculation of the transformation matrix \( \mathbf{A} \) in this case of initial features \( \mathbf{f}_{\text{fr}} \) estimation is prepared in the following steps. First is necessary to find covariance matrix \( \mathbf{C}_{\text{fr}} \) of initial features \( \mathbf{f}_{\text{fr}} \) from the equation

\[
(\mathbf{C}_{\text{fr}} - \lambda \mathbf{I}) \mathbf{e}_i = 0,
\]

where

\( \lambda \) are eigenvalues of covariance matrix \( \mathbf{C}_{\text{fr}} \), which can be found from

\[
\det(\mathbf{C}_{\text{fr}} - \lambda \mathbf{I}) = 0,
\]

where

\( \mathbf{e}_i \) are eigenvectors of covariance matrix \( \mathbf{C}_{\text{fr}} \) of initial features set \( \mathbf{f}_{\text{fr}} \);

\( \mathbf{I} \) - identity matrix.

Finally the principal component transformation matrix \( \mathbf{A} \) is presented and calculated in this case of initial features \( \mathbf{f}_{\text{fr}} \) estimation as composed from eigenvectors \( \mathbf{e}_i \), which are determined from (10):

\[
\mathbf{A} = [\mathbf{e}_1, \mathbf{e}_2, \ldots, \mathbf{e}_n]^T.
\]

The estimation and minimization of initial set \( \mathbf{f}_{\text{fr}} \) of features in form of rectangles is performed, using equation (9), and supposing that some of the eigenvectors \( \mathbf{e}_i \) in (12), which are small can be removed.

The proposed objective estimation and minimization of features in form of rectangles is a way to decrease the time of calculations, when these features are applied in algorithms for objects and people detection and tracking and are implemented in the proposed module for objects and people detection and tracking.

4 Test and results

The presented equation (8) to (12) are used in step of feature estimation and minimization, together with expert evaluation. To achieve good and satisfactory
feature minimization are using a lot of (more than 600) thermal test images. They are preliminary arranged as a thermal images database containing examples of thermal images with objects and people, objects hidden in baggage or dress, like this shown in Figure 3.

Figure 3. An example from the thermal images database of a thermal image with the object hidden in the dress of a person.

The features in form of rectangles (Figure 1 and Figure 2) are calculated for the test thermal images from database. Tables 1-5 present some partial values of the features for the thermal image shown in Figure 3. The values of each of the features are calculated for the chosen important places (Example 1-3 in Tables 1-5) in area of the object, which is seen in thermal image, but it is hidden under the human dress. These places are displayed as black and white templates in the figures from Figure 4 to Figure 8.

It can be seen from the analysis of values in Tables 1-5 that the values of each of the selected features in form of rectangles are different for the chosen in experiments places around the object.

The values of the vertical feature $ftv$ are big in the left and right side of the object also the values of the horizontal feature $fth$ are big in the top and down side of the object, etc.

Table 1

<table>
<thead>
<tr>
<th>Feature</th>
<th>Type “ftv”</th>
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<tr>
<td></td>
<td>Example 1</td>
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<tr>
<td>Left</td>
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<tr>
<td>Right</td>
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Table 2

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<td>1042</td>
</tr>
<tr>
<td>Down</td>
<td>-1292</td>
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<tr>
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<tr>
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<td>905</td>
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Table 3

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<td></td>
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<tr>
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<td>1782</td>
</tr>
<tr>
<td>Right</td>
<td>-1301</td>
</tr>
<tr>
<td>Top</td>
<td>765</td>
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Table 4

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<tr>
<td>Right</td>
<td>3028</td>
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<tr>
<td>Top</td>
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Table 5

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<th>Feature</th>
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<td></td>
<td>Example 1</td>
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<tr>
<td>Position</td>
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<tr>
<td>Left</td>
<td>5448</td>
</tr>
<tr>
<td>Right</td>
<td>2407</td>
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<tr>
<td>Top</td>
<td>4154</td>
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<tr>
<td>Down</td>
<td>2791</td>
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</tbody>
</table>

Figure 4. The places of feature “ftv” as black and white template.
Figure 5. The places of feature “fth” as black and white template.

Figure 6. The places of feature “ftd” as black and white template.

Figure 7. The places of feature “fthl” as black and white template.

Figure 8. The places of feature “ftvl” as black and white template.

The analysis of the results of combination of features in form of rectangles, briefly shown on Table 1-5, and visual observation of the locations of this extraction from Figure 4 to Figure 8 lead to the following results and conclusion:

- the features in form of rectangle for extraction of vertical changes “ftv” in thermal images (Table 1 and Figure 4) are more informative in left and right positions (shaded rows in Table 1);

- for feature “fth” extracting horizontal changes in thermal images (Table 2 and Figure 5) the top and down positions are the places, where the values of these features are largest (Table 2 shaded rows).

The similar deductions can be made also for other features in form of rectangles “ftd”, “fthl”, “fthy” (Tables 3, 4, 5 and Figure 6, 7, 8), which are more informative for diagonal, horizontal and vertical lines, respectively.

The results presented with Table 1 from Table 5 and Figure 3 to Figure 8 described the proposed expert approach to choose informative features in form of rectangles. This approach is combined and examine also with the objective estimation of informative properties of the chosen features using equations from (8) to (12) for calculating principal components. Removing small eigenvectors determined from the transformation matrix \( A \) (equation (12)) is used for the features “ftv”, “fth”, “ftd”, “fthl” and “ftvl” for the thermal images in the created for testing image database. The values of calculated features “ftv”, “fth”, “ftd”, “fthl” and “ftvl” from Table 1 to Table 5 are used in equation (8) as initial value to perform the steps of calculations (equations (8) to (12)).

The results of these calculations are made not only for the examples from Figure 3 to 8 and from Tables 1 to 5, but for all test thermal images (more than 600). A little part of results getting from the informative testing of features using principal component analysis is presented in Figure 9 and Figure 10.
Figure 9. The distribution of values of the features “ftv” and “ftvl” using in the principal component analysis.

Figure 9 show the value distribution of two features in form of rectangles (for detection of vertical edges “ftv” and vertical lines “ftvl”). In Figure 10 are draw two lines as the result of principal component analysis of the chosen two features “ftv” and “fvb”.

Visual estimation of orthogonal location between two lines in Figure 10 toward features distribution lead to conclusion that the feature for vertical lines detection “ftvl” is not informative for the class of objects in thermal images database and can be removed from the list of chosen features in form of rectangles for object detection in thermal images. The operation for removing non informative features is performed as a multiplication of with the set of initial chosen features \( \mathbf{f}_{fr} \) with calculated principal component matrix \( \mathbf{PC} \) for these two features:

\[
\mathbf{PC} = \begin{bmatrix} -0.4735 & -0.8808 \\ -0.8808 & 0.4735 \end{bmatrix}.
\]  

(13)

\[
\mathbf{fr}_E = \mathbf{fr}_j \cdot \mathbf{PC}
\]  

(14)

After proposed and described above feature estimation, minimization with principal component analysis and expert evaluation are carried out the experimental tests for verify the correct work of the chosen and retained after minimization features in form of rectangles. These retained features are only vertical “ftv”, horizontal “fth” and diagonal “ftd”. The experimental tests are made with different images from the thermal images used in step of feature estimation and minimization. These tests images are also includes in the created thermal images database and are chosen with the same important contents of objects and people, objects hidden in baggage or dress.

The results of the experimental tests are presented in form of thermal images after objects or people separation with the proposed minimal set of features in form of rectangles.

An example of correct object detection, separation and labeling is presented on Figure 11 in a test thermal image using the chosen minimal set of features in form of rectangles.

The complete results error estimation of using the proposed set of features for objects detection in thermal images are summarized and are presented in the Table 6. for the created thermal image database with 600 thermal images distributed in groups containing objects, people, people with and without hidden objects in the dress.
Table 6

<table>
<thead>
<tr>
<th>Thermal Images Type</th>
<th>Total Number</th>
<th>Number of Object Detection</th>
<th>Number of Incorrect Detection</th>
<th>Error Rate %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Objects</td>
<td>200</td>
<td>186</td>
<td>14</td>
<td>93%</td>
</tr>
<tr>
<td>People</td>
<td>100</td>
<td>79</td>
<td>21</td>
<td>79%</td>
</tr>
<tr>
<td>People with hidden Objects</td>
<td>250</td>
<td>232</td>
<td>28</td>
<td>92%</td>
</tr>
<tr>
<td>Images without Object or People</td>
<td>50</td>
<td>12</td>
<td>38</td>
<td>76%</td>
</tr>
</tbody>
</table>

The proposed algorithm of estimation of minimal set of features for objects detection in thermal images is addressed to real time processing in a thermal video surveillance system with a preliminary defined precision for a chosen class of object hidden in dress or baggage of people. The chosen set of features is really applied and tested in the development of a real time embedded digital signal processor module described in [3] using Texas Instruments DaVinci Digital Media Processor [10] in the development of a thermo vision information system for customs control and combating terrorism.

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References