Laboratory Approbation of a New Approach for Contrast Enhancement of Human Face Thermal Image Based on Selective Multifunction Pixel Brightness Conversion Function

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Abstract
The paper suggests a new approach to improving the contrast of the thermal image of a person's face in the deep infrared region. The approach involves the analysis and modification of the image histogram and is based on the use of a selective multivalued function for encoding the brightness of image pixels. The approach is focused on processing first of all thermal images of the person face, containing areas with various informativeness. The implementation of the approach in practice makes it possible to improve the contrast of the face image with preservation of all informative features regardless of the level of brightness of the corresponding pixels of the image.
Keywords: Thermal image, Improvement of Contrast, Histogram Modification, Informative Areas

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1. Introduction

Currently, the technology of obtaining and computer processing of the thermal image of the human body is widely used in various fields. Unfortunately, this type of radiation is almost completely absorbed by human clothing. For this reason, in practice, one often has to deal mainly with the thermal imaging of a person's face. The thermal image of a person's face is quite informative. With the use of modern computer processing algorithms, it is possible to determine a number of biometric parameters characterizing the work of its cardiovascular system, its respiratory system, and also its peripheral nervous system [1-3]. The thermal image of a person face is usually characterized by low contrast. The practical algorithms for improving the contrast of the thermal image usually operate with a histogram for the entire image frame. And this leads to significant distortions of personal bio-information and, in extreme cases, even to its complete loss.

For this reason, it is urgent to develop an approach aimed at increasing the contrast of the thermal image of a person's face and guaranteeing the preservation of all significant personal bio-information.

2. Related Work

Currently, there is a fairly large number of scientific publications devoted to solving the problem of improving the contrast of infrared images. The basis in this plan should be considered the approach HE (Histogram Equalization), which allows to improve the contrast of the entire frame of the conventional or infrared image due to the application of the nonlinear function of pixel brightness correction. Unfortunately, the direct application of this approach to the processing of the thermal image of a person's face, as a rule, leads to the loss of personally important bio-information.

In [4-5], the realization of the HE approach for improving the contrast of primarily dark images is considered. It is assumed that the same approach to processing gray tones in the entire image will lead to an improvement in the contrast for the entire image. The informative significance of different areas of the original image is not considered and not taken into account.

In work [7] it is proposed to use the so-called adaptive approach AHE (Adaptive Histogram Equilization). It is based on the analysis and modification of the histogram for the entire image. The AHE approach is primarily aimed at improving the contrast of images with a large proportion of dark areas. For these types of images the approach leads to a significant improvement in contrast. The approach is not intended on thermo image processing with areas of different informativeness.

In the study [8], the authors proposed the CLAHE algorithm (Contrast Limited approach with AHE results) based on a combination of the method for processing non-overlapping image fragments with limited contrast and the above AHE technology [9-12]. This algorithm permits to improve the contrast of the original image, as well as to reduce the noise level. However, it does not guarantee the loss of personal significant bio-information in case of the thermal image of a person's face processing.

3. Histogram and face informative regions

Conducted laboratory studies of 276 thermal images of the human face allowed to obtain a typical histogram. Figure 1 shows the sample of typical histogram obtained for the thermal imaging of a person's face. In Figure 1, the value of I corresponds to the brightness of the pixels of the image. For thermal images in grayscale, this value varies from 0 to 255 for the 8-bit pixel brightness encoding. The value N(I) shows how many pixels of the image have a brightness equal to I.

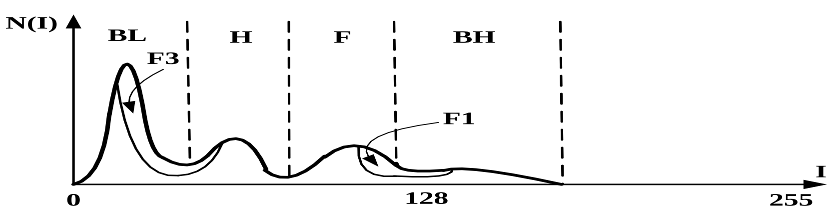


Figure 1: Typical histogram of pixel distribution of thermal image by brightness

The resulting typical histogram in the general case can contain four characteristic regions corresponding to the local maxima of N (I). The BL region includes pixels with a low brightness. The main mass of these pixels is the pixels of the dark background around the head. Area H is characterized by a higher brightness of the pixels compared to the background. This area is mainly made up of image pixels that represent human hair. The brightness of the pixels of the face area F in the absence of strongly heated background elements is usually the maximum. In the presence of hot elements, for example, cups of tea, the BH histogram area has a distinct maximum.

Figure 2 shows an example of a thermal image of a person's face with areas BL, H and F selected on it. Additional hot elements, characteristic for the BH region, are absent in this example.

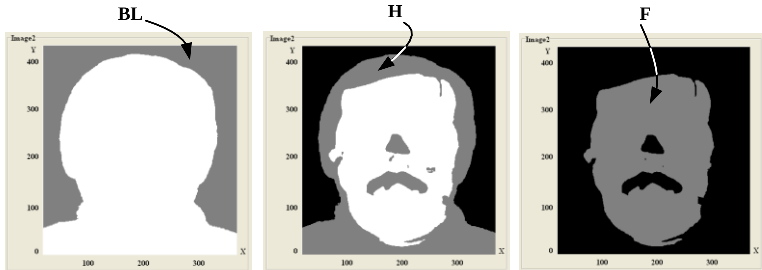


Figure 2: Characteristic areas F, H and BL of the thermal image of the face

The pixels of the BL, H and F areas are highlighted in gray. Pixels of white color refer to areas with a brightness greater than the selected areas of gray. Accordingly, pixels of black color characterize parts of the image with a brightness lower than the selected gray ones.

In view of the particular informativeness of the face area F, an in-depth analysis was carried out. This analysis made it possible to distinguish three subregions - F1, F2 and F3, presented in Figure 3. The subregion that characterize respectively the highest temperature in the eye and mouth (F1), have a sufficiently high temperature in the forehead and chin area (F2), and also a relatively high temperature, usually in the cheek area (F3). Similar to Figure 2 in Figure 3, the subregions F1, F2 and F3 are highlighted in a gray background. And white and black areas correspond accordingly with a higher and lower brightness.

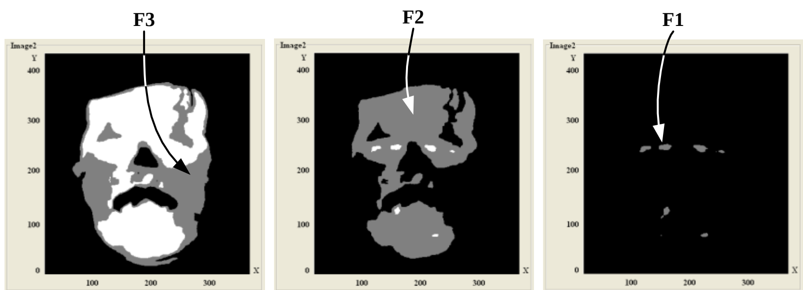


Figure 3: Dedicated subregions

The main problem with the use of traditional algorithms for improving the contrast of the thermal image of a person's face is that his most informative eye and the bottom of the nose areas are partially, and in the worst case completely located on the histogram in the BL and BH regions, respectively. And these areas under the application of traditional algorithms are subjected to maximum distortion.

4. Traditional algorithms for contrast improvement

Many traditional contrast enhancement algorithms use pixel brightness conversion on the basis of the nonlinear function $I^*(I)$, the typical form of which is shown in Figure 4 [10-12]. The value of I corresponds to the original pixels brightness, and the value of I^* corresponds to the pixels brightness after the conversion. The specific form of this function is usually determined by the boundaries of the separation of the selected regions BL, H, F and BH, and also by the points $I1^*$ and $I2^*$. The latter determine the degree of data compression in the areas BL and BH. After the conversion, the dynamic range of the most interesting regions H and F expanded and became determined by the range of values from $I1^*$ to $I2^*$. In the limiting case, this range can be increased to $I1^* = 0$ and $I2^* = 255$ for images in grayscale. For thermal images with low contrast, for which the boundaries between the areas BL and

H, as well as F and BH, for example, have values of 64 and 128, respectively, the gain in contrast can reach 3-4 times.

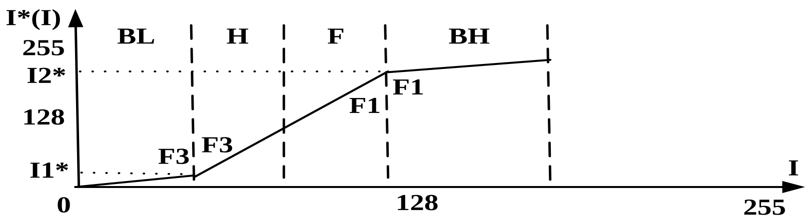


Figure 4: Typical view of pixel brightness conversion function

A new histogram is shown in Figure 5. Its advantage is that the contrast of the image for the new regions F* and H* has increased significantly. For these areas, the brightness was converted linearly, which does not lead to distortion or loss of meaningful information. Unfortunately, at the same time, part of the informative pixels F1 and F3, located in the BL and BH regions, undergo the brightness conversion with the contrast deterioration. This leads to a loss of meaningful information and a decrease in the reliability and accuracy of remotely sensed human bio-parameters.

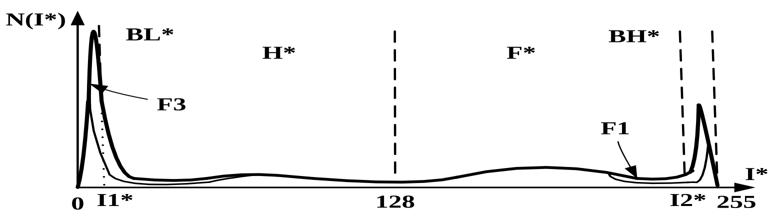


Figure 5: New histogram after brightness conversion

5. The proposed approach

The main idea of the proposed approach is to use the multivalued selective function of brightness conversion, which allows to increase the contrast of the thermal image of a person's face without losing significant information. One of the variants of the corresponding brightness conversion function is shown in Figure 6. The sections a-b and c-d are intended for the brightness conversion of the pixels belonging to the histogram areas of BL and BH respectively and not belonging to the image of the face area. The area of the e-f function is used to converse the brightness of only the pixels belonging to the face image. The selection of pixels by their belonging to the face area is carried out on the basis of pixel coordinates comparison with face image boundaries.

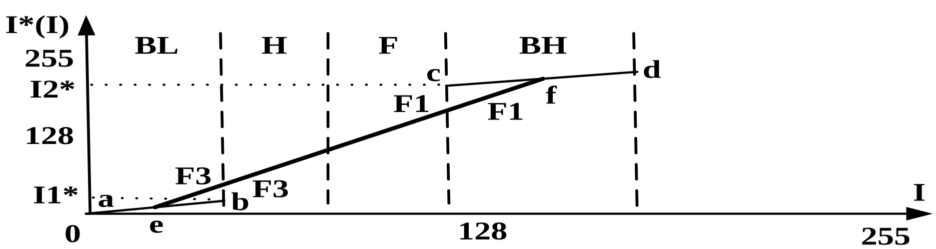


Figure 6: Multivalued selective brightness conversion function

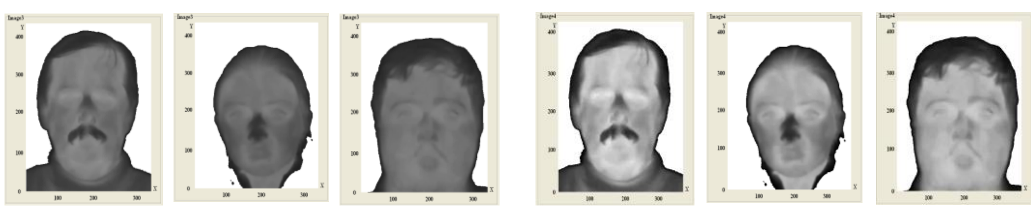
Thus, the proposed approach makes it possible to carry out data compression for the BL and BH regions in a manner similar to the traditional BE approach. At the same time, the proposed approach allows to preserve the linearity of the brightness conversion of all the pixels that represent the face image. First of all, this concerns the pixels of the most informative areas F1 and F3.

So, the proposed approach includes the following basic operations:

1. The original thermal image histogram N(I) of a person's face calculation. Identification of the characteristic regions BL, H, F, and BH on the basis of its extremum analysis.
2. Determination of the boundaries of the human head based on the pixels coordinates analysis of the regions H and F. Determination of the key points I1* and I2* based on the specified requirements for the allowable data compression ratio in the areas BL and BH.
3. Determination of the e-f section allowable slope for the new conversion function I*(I) from the boundaries of the informative areas F1 and F2.
5. Determination the main parameters of the new multivalued selective recoding function I*(I) on the basis of the data obtained in clauses 4 and 5. Conversion of the pixels brightness based on the received function I*(I).

6. Experimental results

The proposed approach was realized in the form of a specialized image processing program Termo_Image_C. Based on the available library of thermal images of individuals, a laboratory approbation of the proposed approach was carried out. Thus, Figure 7a presents examples of the initial thermal image of a person's face with a rather poor contrast. Figure 7b shows the obtained images with improved contrast. In Figure 7, the external dark background is replaced by white for a more embossed display of the head boundaries. It is visible, that the most informative areas F1 and F3 became more contrast. On average, the contrast gain is 2.5 times. The contrast of the area was defined as the ratio of the brightness of the pixels of the given region with the maximum brightness to the brightness of the pixels with the minimum brightness.



a) b)

Figure 7: Laboratory approbation of the proposed approach: a - typical examples of the initial thermal image of a person's face; b - improvement of the contrast of images on the basis of the proposed approach

8. Conclusion

The selective multivalued function of pixel brightness recoding I*(I), considered in this work, makes it possible to take a new approach to solving the problem of improving the contrast of the thermal image of a person. It allows, on the one hand, to provide a high data compression ratio for background areas and, on the other hand, to guarantee a significant improvement in the contrast of the most informative areas of the face without loss of personal information. Implementation of this approach is characterized by low computational complexity. For this reason, it can be recommended for use in real-time image processing systems. Conducted laboratory approbation of the approach confirmed its high reliability and efficiency.

Application of this approach in practice will increase the reliability and accuracy of remote determination of human biomaterials using the actively developing infrared monitoring technologies. This is of great importance, first of all, for monitoring systems for the current functional and psycho-emotional state of a person. These systems are one of the key elements allowing to guarantee trouble-free operation of hazardous objects, for example, nuclear power plants.

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