Top-Hat transform for enhancement of aerial thermal images

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***Abstract*—A thermal image is obtained by a camera that is sensitive to the thermal variation of the environment. This sensitivity in most cases affects the quality of the image obtained. Therefore, it is very important to improve the quality of thermal images in terms of contrast and details. There are different contrast enhancement techniques which introduce minor distortions, preserving the proper brightness as well as the details of the image. This work presents a top-hat transform for the improvement of grayscale aerial thermal images. The proposed method is based in the use of increasing structuring elements of similar geometry within the fundamental operations of mathematical morphology. The evaluation of the performance of the current proposed method was made with several metrics for images in grayscale. The experimental results show that the proposed method improves several thermal images which were tested, enhancing the contrast, preserving the richness of the details as well as the mean brightness and introducing less distortion in the images. The results show better aerial thermal images with less distortion and adequate brightness, which is very useful for further processes over the images.**

I. Introduction

Applications that use aerial thermal imaging are diverse. In addition to their use in military applications, they are being used in the detection and search of individuals [1], [2]. Other applications of thermal imaging are seen in the food and agriculture industries, where they measure the temperature of the fruit as it matures [3]. In the biomedical sciences there are applications such as breast cancer detection [4] and body temperature change detection caused by some diseases [5].

Thermal images, in contrast to visible images, have a high background intensity and low contrast. This means that there is a small difference between the objects and the background intensity, which hinders the observation and recognition of individuals within these types of images. For this reason, contrast enhancement is an important step in applications using aerial thermal imaging. Different types of algorithms have been proposed to improve the images. The algorithms based on histograms [6], [7] improve the bright regions of the images, but do not maintain the naturalness of the images because of inadequate brightness [8], therefore there are variations of these algorithms that perform the improvement maintaining the mean brightness of the images [9], [10]. Mathematical morphology [11]–[14] is an important tool used in contrast enhancement, proposed by Matheron and Serra [11] for image analysis. The top-hat transform is an important method for image processing. With the top-hat transform the bright and dark regions of the images are obtained, then the image is improved by adding bright regions and removing the dark regions of the original image [12], [14], [15].

In this work a top-hat transform is presented, which uses the basic operations of mathematical morphology, increasing structuring elements of similar geometry. The proposed method was applied to grayscale aerial thermal images from a public image database [1].

The work is organized as follows: Section II presents the basic concepts of mathematical morphology. Section III presents the top-hat transform proposed with increasing structuring elements of similar geometry. In section IV the experimental results are shown. The conclusions and future works are presented in section V.

II. Mathematical morphology

Mathematical morphology has been an important mathematical theory for image processing [14]. Morphological operations are based on set theory and work with two sets, the original image and the structuring element. The two basic mathematical morphology operators are erosion and dilation [16].

Let I be the image and H a structuring element whose pixels are represented by cartesian coordinates (u, v) and (i, j), respectively. The grayscale dilation $I \oplus H$ is defined as the maximum of the values in H added to the values of the current sub-image of I,

$$(I \oplus H)(u, v) = \max_{(i,j)\in H}\{I(u + i, v + j) + H(i, j)\} \quad (1)$$

Similarly, the result of grayscale erosion is the minimum of the differences,

$$(I \ominus H)(u, v) = \min_{(i,j)\in H}\{I(u + i, v + j) - H(i, j)\} \quad (2)$$

Dilation and erosion will be denoted below as $(I \oplus H)$ and $(I \ominus H)$ respectively, for all cartesian coordinates (u, v).

There are some more composite operations, like opening and closing [16].

A grayscale opening $(I \circ H)$ denotes an erosion followed by a dilation with the same structuring element H,

$$(I \circ H) = (I \ominus H) \oplus H \quad (3)$$

When the erosion and dilation sequence is reversed, the resulting operation is called closing and denoted $(I \bullet H)$,

$$(I \bullet H) = (I \oplus H) \ominus H \quad (4)$$

Using opening and closing, the white top-hat transform (WTH) and the black top-hat transform (BTH), are defined as follows [17],

$$WTH = I - I \circ H \quad (5)$$

$$BTH = I \bullet H - I \quad (6)$$

Opening smoothes bright regions of the image and closing smoothes dark regions. Thus, WTH discovers bright regions and BTH gives dark regions in I [11].

The contrast enhancement of I based on the top-hat transform consists of adding bright regions and subtracting dark regions from I as follows [14]:

$$I_E = I + WTH - BTH \quad (7)$$

where I_E is the resulting image with contrast enhancement.

III. Proposed method

The main idea is to apply top-hat transforms, using structuring elements of similar geometry with different scales. More recent works that use different structuring elements in the top-hat transform exist in the literature, but do not retain the exact geometry of the structuring elements [18], [19].

Let SE be a convex structuring element, $(n-1)$ the number of dilations for SE_n in a range $i = 1, 2, \cdots n$ and $(m-1)$ is the number of dilations for SE_m in a range $j = 1, 2, \cdots m$, as follows:

$$SE_n = SE_{n-1} \oplus SE = \underbrace{SE \oplus SE \oplus SE \oplus \cdots \oplus SE}_{\textit{n-1 dilations}}$$

$$SE_m = SE_{m-1} \oplus SE = \underbrace{SE \oplus SE \oplus SE \oplus \cdots \oplus SE}_{\textit{m-1 dilations}}$$

Therefore, we define the structuring elements H_1 and H_2 as follows:

$$H_1 = SE_n \quad (8)$$

$$H_2 = SE_m \quad (9)$$

where H_1 and H_2 are flat and geometrically proportional, because the base structuring element SE is convex.

Considering the increasing structuring elements, the top-hat transform is defined as follows:

$$WTHN = I - ((I \ominus H_1) \oplus H_2) \quad (10)$$

$$BTHN = ((I \oplus H_1) \ominus H_2) - I \quad (11)$$

Finally the contrast enhancement of the image will be obtained as follows:

$$I_{EN} = I + WTHN - BTHN \quad (12)$$

where I_{EN} is the image with contrast enhancement. In case $H_1 = H_2$, equation (12) equals equation (7).

Figure 1 shows: (a) the original image, (b) the enhanced image with equation (7) and (c) the enhanced image with equation (12). In the enhanced image with equation (12), we can identify that the details and the focus of the image are presented with less distortion, this makes possible the recognition of the objects within the aerial thermal image.

In the next section we will see the experimental results obtained from comparing the proposed method with other contrast enhancement algorithms.

IV. Experiments and results

The results for aerial thermal images are presented below, as well as the metrics used to measure the quality of the resulting image.

For comparison purposes, histogram-based contrast enhancement algorithms were used, and also an algorithm using the top-hat transform. Histogram Equalization (HE) [20] performs a global enhancement of the image and Contrast Limited Adaptive Histogram Equalization algorithm (CLAHE) [21] performs a local enhancement. The multiscale morphological contrast enhancement MMCE [15], which uses multiscale processes, was used to perform contrast enhancement based on the top-hat transform.

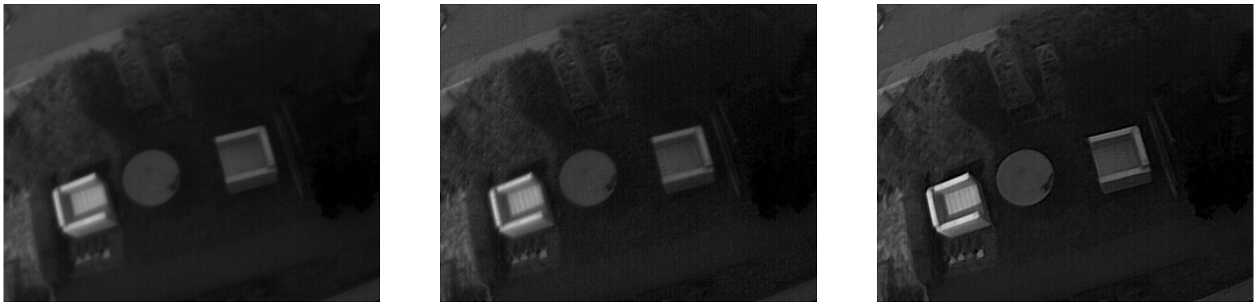
Three metrics were used to assess the image enhancement.

- The *Standard Deviation* (TD) was used to quantify the global contrast enhancement in grayscale images, it is defined as [22]:

$$DT(I) = \sqrt{\sum_{k=0}^{L-1} (k - E(I))^2 \times p(k)} \quad (13)$$

  where k represents the value of the pixel (u, v) of the image I, the levels of gray are represented by L, the mean intensity of the image is represented by $E(I)$ and $p(k)$ is the probability of occurrence of the value k. The $DT(I_{EN})$ value of the resulting image must be greater than the $DT(I)$ of the original image to assume enhancement.
- The metric adopted to measure the signal-to-noise ratio of an image is the *Peak Signal-to-Noise Ratio* (PSNR). Given a reference image I and an test image I_{EN} where the size of the images is $M \times N$, the PSNR between I and I_{EN} is defined as [15]:

$$PSNR(I, I_{EN}) = 10 \times log_{10} \frac{(L-1)^2}{MSE(I, I_{EN})} \quad (14)$$



(a) (b) H is 3×3 square (c) H_1 is 3×3 square and H_2 is 5×5 square

Fig. 1. (a) original image, (b) enhanced image with equation 7 and (c) enhanced image with equation 12.

where the *Mean Squared Error* (MSE) is defined as:

$$MSE(I, I_{EN}) = \frac{1}{M \times N} \sum_{u=0}^{M-1} \sum_{v=0}^{N-1} (I(u,v) - I_{EN}(u,v))^2 \quad (15)$$

- The *Absolute Mean Brightness Error* (AMBE) [23], which is defined as the absolute difference between the mean brightness of the input image and the resulting image, is given by:

$$AMBE(I, I_{EN}) = |E(I) - E(I_{EN})| \quad (16)$$

  where I and I_{EN} represent the input image and the resulting image, respectively, $E(I)$ and $E(I_{EN})$ represent the mean brightness of the input image and the resulting image. The AMBE measures the performance in preserving the original brightness and the lower its value, the better the conservation of brightness.

For the testing 200 aerial thermal images (obtained from a public database [1]) were used. The tests were performed with the algorithm HE, CLAHE, MMCE and the proposed method. The HE and CLAHE algorithms were implemented using the Image Processing Toolbox of MATLAB [21] (using the default parameters).

For the experiment 1 and 2 convex structuring elements at different scales were used. The objective of these experiments is to measure the behavior of the values DT, PSNR and AMBE.

IV.1. Experiment 1

For the experiment 1 the structuring elements have similar areas. The number of iterations for the MMCE algorithms were $q = 3$. For the proposed method $n = 3$ and $m = 4$. The initial structuring element SE is square and is of size 3×3 for both algorithms.

Figure 2 shows: (a) the original image *90.png*, (b) the enhanced image with the HE algorithm, (c) the enhanced image with the CLAHE algorithm, (d) the enhanced image with MMCE and (e) the enhanced image with the proposed method. The enhanced image with the HE and CLAHE algorithm improves contrast, but generates a lot of distortion by introducing inadequate brightness. Enhanced image with MMCE introduces distortions, but improves contrast. The enhanced image with the proposed method presents more defined objects, enhances the contrast, maintaining the appropriate brightness of aerial thermal images.

Figure 4 shows the zoom of the image obtained with the proposed method, the image shows less distortion. While Figure 3 shows the zoom of the image obtained by the MMCE algorithm, it presents distortions in the image.

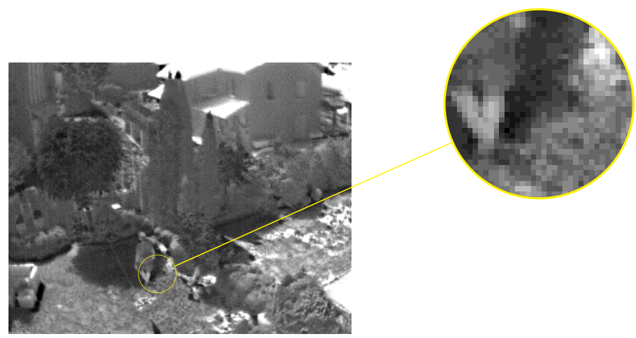


Fig. 3. Zoom of the image with contrast enhancement obtained by MMCE algorithm.

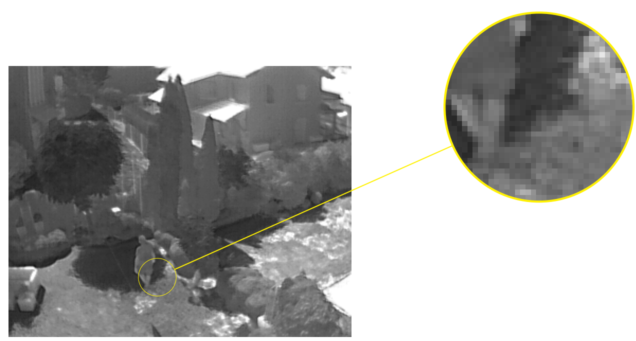


Fig. 4. Zoom of the image with contrast enhancement obtained by proposed method.

Figure 5 shows: (a) the original image *295.png*, (b) the enhanced image with the HE algorithm, (c) the enhanced

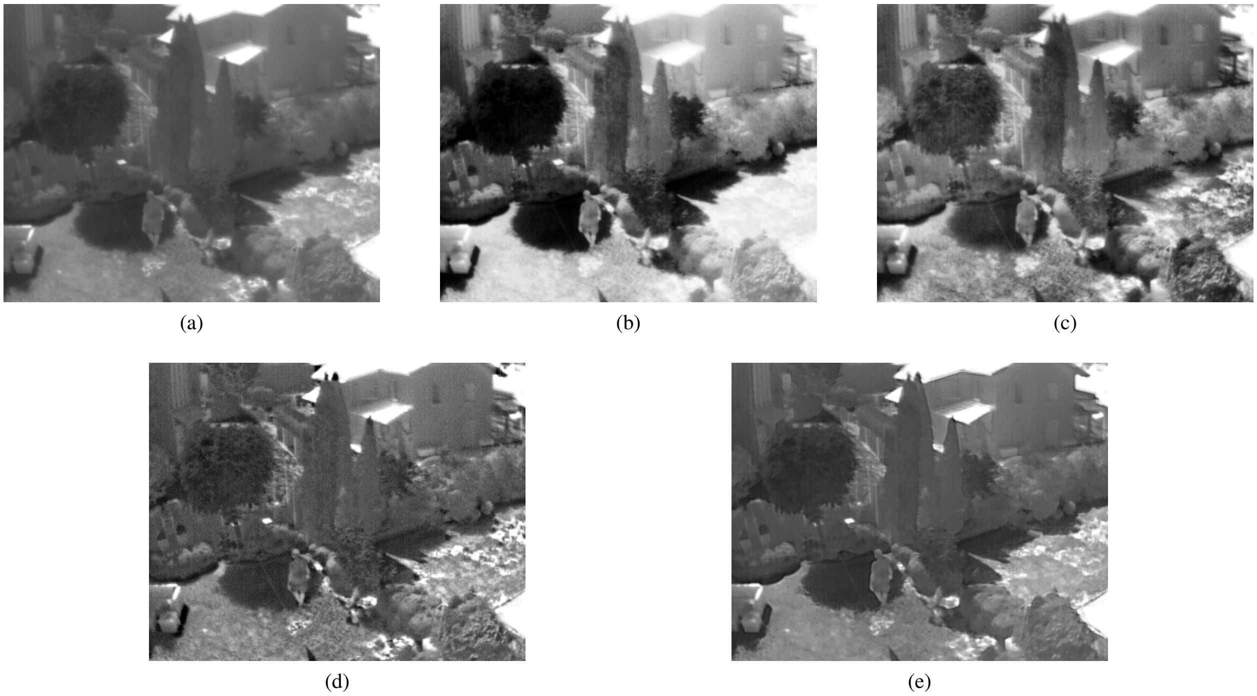


Fig. 2. (a) original image *90.png*, (b) enhanced image with the HE algorithm, (c) enhanced image with the CLAHE algorithm, (d) enhanced image with MMCE and (e) enhanced image with the proposed method.

image with the CLAHE algorithm, (d) the enhanced image with MMCE and (e) the enhanced image with the proposed method. The improved image with the HE algorithm introduces improper image brightness losing the person and the animal, while the CLAHE does the same in a smaller proportion. Improved image with MMCE introduces disturbances in the thermal image. The proposed method presents the person and the animal with a well defined details and it improves the contrast.

Figure 6 shows: (a) the original image *520.png*, (b) the enhanced image with the HE algorithm, (c) the enhanced image with the CLAHE algorithm, (d) the enhanced image with MMCE and (e) the enhanced image with the proposed method. The HE algorithm greatly increases the brightness. The CLAHE introduces noise and brightness to a lesser extent than the HE in the thermal image. Improved image with MMCE introduces distortions in the thermal image. Image processed with the proposed method shows clear details with respect to the original image and contrast enhace of the thermal image.

Figure 8 shows the zoom of the image obtained with the proposed method and Figure 7 the zoom of the image obtained with the MMCE algorithm. The image obtained with the proposed method is visually more attractive.

From the results shown in Table I, we can see that the algorithm HE improves the contrast of the thermal image, but distorts and loses the mean brightness. CLAHE improves contrast, distorts to a lesser degree with respect to HE and also loses the mean brightness. MMCE improves contrast, introduces distortions to the image in lesser proportion and retains the mean brightness. The proposed method increases the contrast, preserves the mean brightness of the thermal image and distorts the image to a lesser extent than the other algorithms.

From the results shown in Table II, we can see that the higher iteration, the higher contrast, but the image is more distorted, causing the loss of the mean brightness.

TABLE I
EXPERIMENT 1: NUMERICAL AVERAGES OBTAINED FROM THE 200 AERIAL THERMAL IMAGES.

Methods	DT	PSNR	AMBE
I	38,671		
HE	**74,763**	12,610	45,651
CLAHE	47,853	18,657	16,835
MMCE	42,291	27,702	0,249
Proposal	40,152	**33,180**	**0,174**

TABLE II
EXPERIMENT 1: NUMERICAL AVERAGES OBTAINED FROM THE 200 AERIAL THERMAL IMAGES WITH THE MMCE ALGORITHM.

Iter.	DT	PSNR	AMBE
1	39,458	**35,724**	**0,111**
2	41,376	28,821	0,285
3	42,291	27,702	0,405
4	43,107	26,922	0,626
5	43,908	26,263	0,685
6	44,793	25,570	0,875
7	**45,749**	24,889	1,042

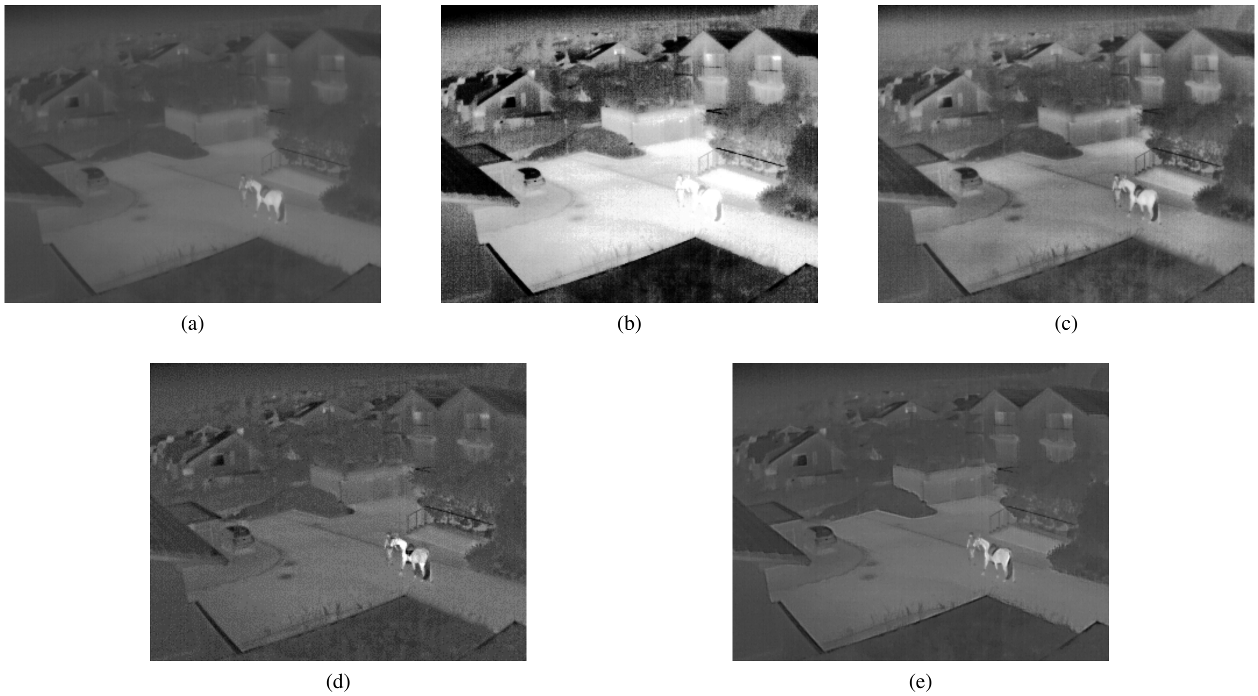


Fig. 5. (a) original image *295.png*, (b) enhanced image with the HE algorithm, (c) enhanced image with the CLAHE algorithm, (d) enhanced image with MMCE and (e) enhanced image with the proposed method.

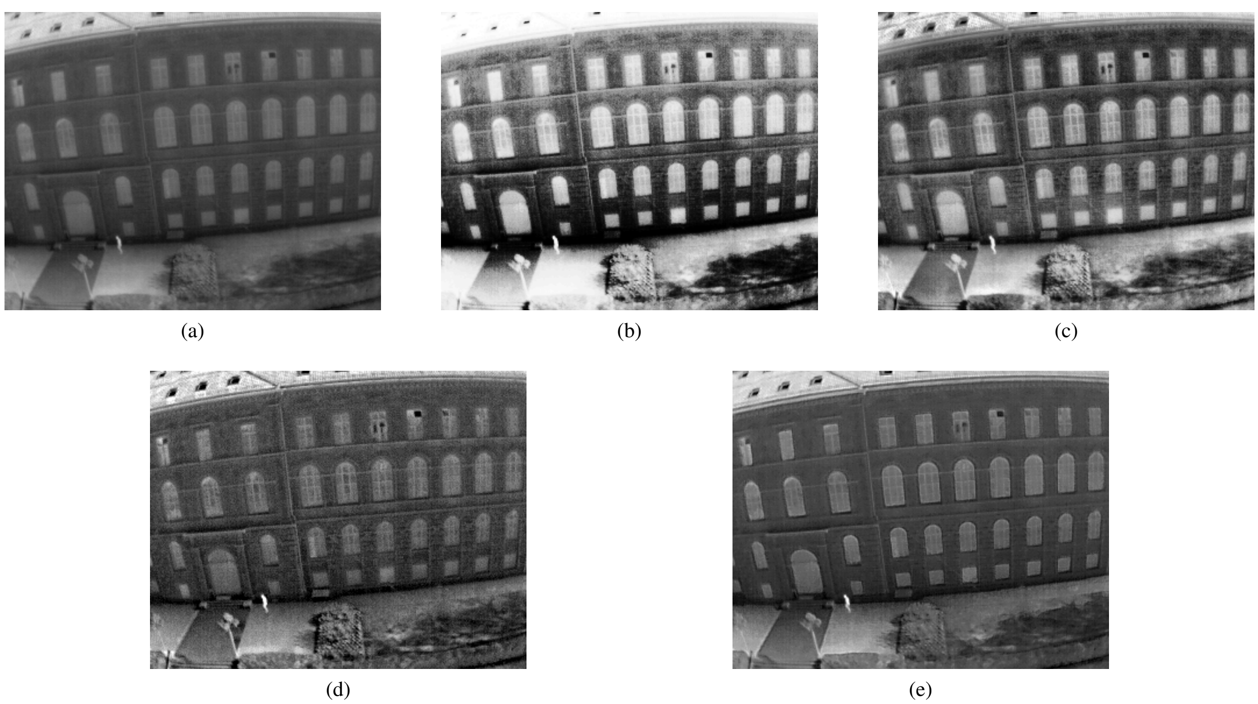


Fig. 6. (a) original image *520.png*, (b) enhanced image with the HE algorithm, (c) enhanced image with the CLAHE algorithm, (d) enhanced image with MMCE and (e) enhanced image with the proposed method.

From the results shown in Table III, we can observe that the larger the structuring elements and similar areas, the less noise is introduced and the mean brightness is conserved. But the contrast of the thermal image is improved to a lesser extent.

IV.2. Experiment 2

For the experiment 2, the structuring elements have very different areas. The number of iterations for the MMCE

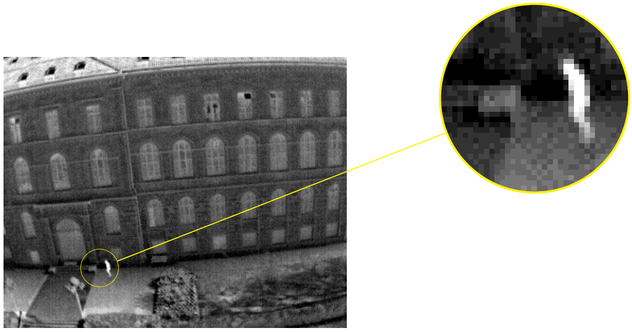


Fig. 7. Zoom of the image with contrast enhancement obtained by MMCE algorithm.

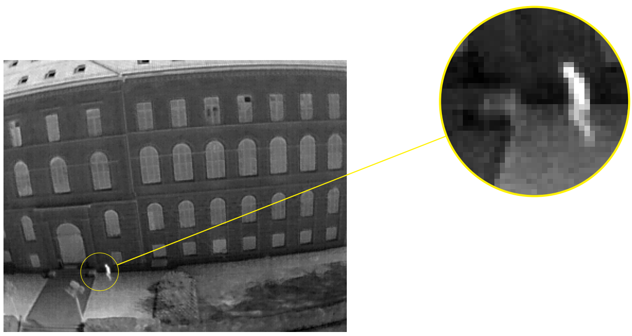


Fig. 8. Zoom of the image with contrast enhancement obtained by proposed method.

TABLE III
EXPERIMENT 1: NUMERICAL AVERAGES OBTAINED FROM THE 200 AERIAL THERMAL IMAGES WITH THE PROPOSED METHOD.

Test	H1	H2	DT	PSNR	AMBE
1	3×3	5×5	**40,397**	31,855	**0,155**
2	5×5	7×7	40,274	32,558	0,160
3	7×7	9×9	40,152	33,180	0,174
4	9×9	11×11	40,061	33,710	0,192
5	11×11	13×13	40,001	34,136	0,215
6	13×13	15×15	39,878	34,905	0,243
7	15×15	17×17	39,942	**34,516**	0,234

algorithms were $q = 7$. For the proposed method $n = 1$ and $m = 7$. The initial structuring element SE is square and it is of size 3×3 for both algorithms.

Figure 9 shows: (a) the original image *520.png*, (b) the enhanced image with MMCE and (c) the enhanced image with the proposed method. Improved image with MMCE introduces to a lesser extent distortion in the thermal image. Improved image has better contrast, but introduces more distortions to the image.

From the results shown in Table IV, we can see that the MMCE algorithm improves the aerial thermal image in terms of mean brightness. The equation 7 that uses the concept of top-hat by reconstruction introduces less distortions. The proposed method improves contrast.

In geodesy, the fundamental concept of its development is connectivity. Geodesic reconstruction is the most important

TABLE IV
EXPERIMENT 2: NUMERICAL AVERAGES OBTAINED FROM THE 200 AERIAL THERMAL IMAGES.

Methods	DT	PSNR	AMBE
I	38,671		
MMCE	45,749	24,889	**1,042**
I_E	40,783	**33,173**	2,099
Proposal	**51,730**	21,210	2,677

TABLE V
EXPERIMENT 1: NUMERICAL AVERAGES OBTAINED FROM THE 200 AERIAL THERMAL IMAGES WITH THE CONTRAST ENHANCEMENT USING TOP-HAT BY RECONSTRUCTION.

Test.	H1	DT	PSNR	AMBE
1	3x3	38,848	**44,895**	**0,427**
2	5x5	39,116	40,474	0,701
3	7x7	39,378	38,239	0,953
4	9x9	39,632	36,727	1,203
5	11x11	39,956	35,430	1,465
6	13x13	40,419	34,028	1,793
7	15x15	**40,783**	33,173	2,099

TABLE VI
EXPERIMENT 2: NUMERICAL AVERAGES OBTAINED FROM THE 200 AERIAL THERMAL IMAGES WITH THE PROPOSED METHOD.

Test.	H1	H2	DT	PSNR	AMBE
1	3×3	5×5	40,397	**31,855**	**0,155**
2	3×3	7×7	42,659	27,343	0,417
3	3×3	9×9	44,805	25,106	0,807
4	3×3	11×11	46,772	23,683	1,238
5	3×3	13×13	48,591	22,642	1,692
6	3×3	15×15	50,240	21,846	2,176
7	3×3	17×17	**51,730**	21,210	2,677

operation within geodesy [24]. For this reason, we used the top-hat concept for reconstruction in the following experiment and applied it in equation 7 to improve the contrast of aerial thermal images. Table V shows the results for the 200 aerial thermal images, which were obtained by applying the top-hat by reconstruction in equation 7.

From the results shown in Table VI, we can see that the greatest difference in the areas of structuring elements gives rise to greater contrast, but the thermal image is more distorted, causing the loss of natural brightness.

V. CONCLUSIONS AND FUTURE WORK

This work proposes a top-hat transform, which uses increasing structuring elements of similar geometry in the basic operations of mathematical morphology. The efficiency of the proposed method was evaluated with different metrics that measure the contrast enhancement, the conservation of the mean brightness and the signal-to-noise ratio of the image.

When the size of the structuring elements is greater and when the difference between the areas H_1 and H_2 is minimal, lower distortions and better mean brightness are obtained. The contrast enhancement is minimal compared to the original image. With this proposed method objects or individuals in the

(a) (b) (c)

Fig. 9. (a) original image *520.png*, (b) enhanced image with MMCE and (c) enhanced image with the proposed method.

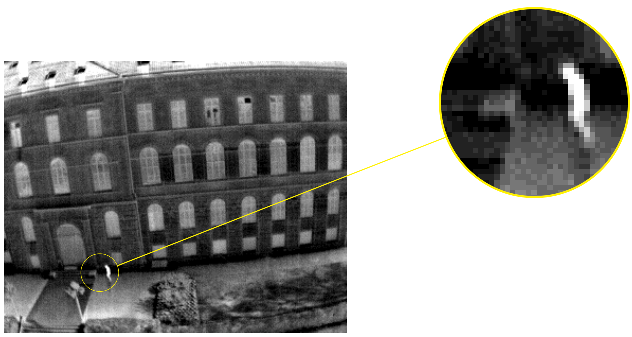


Fig. 10. Zoom of the image with contrast enhancement obtained by MMCE algorithm.

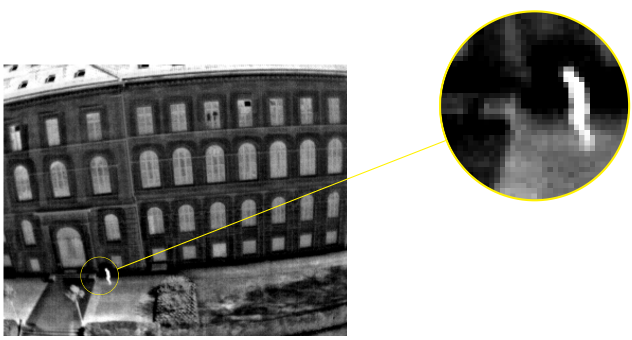


Fig. 11. Zoom of the image with contrast enhancement obtained by proposed method.

images are better identified. When the structuring elements are of very different areas, it enhances the contrast and introduces distortions to the image.

The visual and numerical results show that this new general strategy improves aerial thermal images, enhances contrast and preserves the mean brightness of images, according to the size of the structuring elements.

For a future work it is intended to apply the proposed method to images of other types, as well as to color images. Apply the proposed method in applications such as segmentation of images, fusion of images, detection of objects, among others.

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