КАРТОГРАФІЯ І АЕРОФОТОЗНІМАННЯ

CARTOGRAPHY AND AERIAL PHOTOGRAPHY

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USING INVERSE FILTERING TO INCREASE THE RESOLUTION IR IMAGES

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The aim of the work is to increase the resolution of IR images obtained as a result of monitoring thermal objects. **Methodology**. It is known, an optical system can not date a CCD point picture thermal object. Instead picture diffraction spots, have significant deterioration in quality thermal image which has a reduced effect with defraction. This is an urgent system task useful in the formative and processing signal. To achieve this goal, it is suggested to use the method of reverse filtration, which allows, knowing the function of point dispersion (FPD) of the optical system caused by the phenomenon of diffraction, to significantly reduce its effect on the quality of the resulting image. In the optics-computer system, the optical image is projected onto a CCD matrix, de FPD which is already presented in digital form. This method based on reverse filtration [Rabiner et al., 1978]. It is believed that blur is an irreversible operation and information is irretrievably lost, because every pixel turns into a spot and everything mixes. **Results**. In fact, all information is simply redistributed in accordance with the FPD and can be uniquely restored with some reservations. The proposed technique for using the reverse filter algorithm allows us to overcome the limitations imposed by the optical system. **Scientific novelty.** The authors propose to use the specially developed digital measures and the program of two-convolution convolution (convolution) of these images with FPD to determine the effect of the FPD values on the resolution of the monitoring system. **Practical significance**. The developed algorithm of reverse filtration (deconvolution) together with other methods (for example, sub-pixel processing) can be successfully used for processing IR images obtained as a result of remote monitoring of thermal objects. The deconvolution method allows overcoming the limitations on the resolution that are imposed by the optical system in the infrared range. This leads, in the absence of noise, to an accurate reproduction of the input image of the thermal object, regardless of the diameter of the world spot. The difference in the values of the FPD optics and the FPD model, which were used in the implementation of convolution and deconvolution programs, is of decisive importance. Especially important are the results of the operation of the method of reverse filtration under the conditions of noise on the thermal image and in the data transmission channel. The value of the signal-to-noise ratio at which the distortions are considered as insignificant is determined. At the same time, as the studies show, the magnitude of the photoluminescence spot of the objective is important. The question of application of the proposed method of reverse filtration in the case of uncertainty of lens data, which was used in thermal monitoring, is often encountered in the practice of processing thermal imagery available to the user. All the results obtained are verified on imitation models, which is the additional novelty and practical significance of the results obtained.

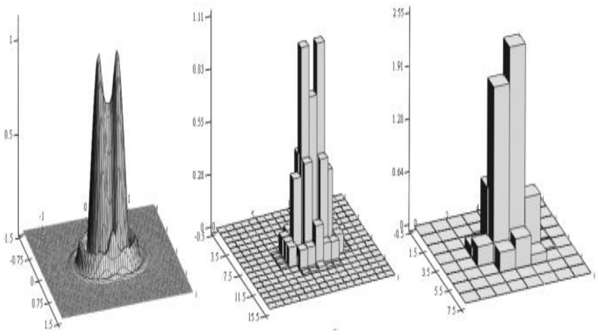
Key words: resolution; lens; the scattering function of a point; model; convolution; deconvolution.

Introduction

When processing the infrared images obtained during remote monitoring of thermal objects, a blurring problem arises. It is known that any optical system can create a clear pixel image on a device with a charge device (CCD) of the matrix. FPD can be obtained experimentally or presented analytically. The latter is convenient for researching and developing algorithms for digital image processing [Gashnikov, 2003]. To evaluate the algorithms, one of the possible expressions for FPD (1) was used:

$$a := 1 \qquad b := 1.3$$

$$f(x,y) := e^{\frac{-(x^2+y^2)}{2a}} \cdot \cos\left[\frac{(x^2+y^2)}{2a} \cdot b\right]^2 \quad \text{.....} \quad \text{.......(1)}$$



a *b* *c*

Fig. 1. The intensity of the image of two neighboring points

The optical image is projected onto a CCD array. Since in the optical range many lenses of resolution exceed the resolution of the matrices, it is believed that the more pixels in the matrix, the more small details of the object can be obtained in the picture. Obviously, no, as even the most ideal matrix, can see the details that the lens could not distinguish. In Figure 1 below shows the intensities of the images of two points at a distance corresponding to the Rayleigh criterion (a). This image is digitized by CCD matrices (b, c). If the linear size of the pixel is less than or equal to the radius of the Airy disk, then the points are seen separately (b).

Purpose of the study

Reducing the pixel size can not improve resolution. If the pixel size is larger, for example, equal to the diameter of the Airy disk, then the image of the points merge (c) It is considered that the resolution is fundamentally limited by diffraction in the optical system of the apparatus. However, in the optics-computer system, this limitation is not so important. The resolution of the complex depends on the optical system, the method of forming the frame on the IR matrix and the algorithm for digital processing, it is advisable to estimate the resolution separately. [Pereslavtseva 2012.]. Perhaps a digital representation for the FRT:

$$\text{ФРТ} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.11 & 0.11 & 0.11 & 0 & 0 \\ 0 & 0 & 0.11 & 0 & 0.42 & 0 & 0.11 & 0 \\ 0 & 0 & 0.11 & 0.42 & 1 & 0.42 & 0.11 & 0 \\ 0 & 0 & 0.11 & 0 & 0.42 & 0 & 0.11 & 0 \\ 0 & 0 & 0 & 0.11 & 0.11 & 0.11 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix}$$

The disk of Eyri is shown in Fig. 2

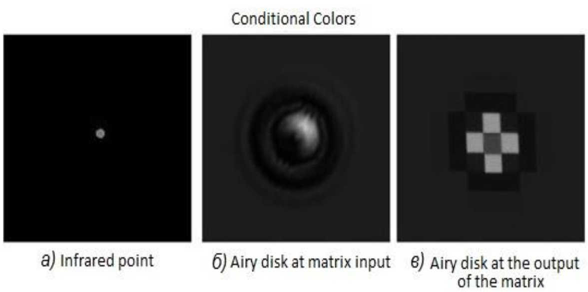


Fig. 2. Airy Disk

Located in the focal plane, the IR matrix transforms the FPD into a digital form (c). The pixel size in this figure is equal to the radius of the Airy disk. To remove the real-lens FPD, for example, it is possible to use an IR diode, placing it in the focal plane of an additional lens, which at the input of the lens will form an IR diode at infinity, so that the image can be considered as a dot. From the point of view of digital signal processing, the optical system can be considered as a two-dimensional linear digital filter with a pulse response corresponding to the FPD in digital form. Impulse response is called the filter response per unit pulse (Kronecker pulse) is presented at its input [Gonzalez, 2006]. The pulse response of the digital filter (DF) fully and unambiguously describes its properties. There are no additional characteristics of a linear DF, which would be impossible to obtain with an impulse response. In order to obtain an image of the measure at the output of the lens, it is necessary to perform the two-dimensional convolution (convolution) of the measure and the FPD. This operation is the model of the lens. In Fig. 3 shows the result of the convolution of Mira-3 and FPD, that is, the Mira-3 image in the focal plane of the objective.

Fig. 3. Image of the Mira-3 at the entrance and exit of the lens

Since the model of the objective with FPD is used, which is not a single Kronecker pulse, so the Mira-3 image is very blurry. The task is to eliminate the blurriness and restore the original image of the world if the FPD of the lens is known. It is commonly believed that blurring is an irreversible operation and that information is irretrievably lost, because when each pixel turns into a spot, everything mixes, and if the blur radius is large, we get a uniform color throughout the image [Zhang Ningyu 2007] In fact, all information is simply redistributed into compliance with the FPD and can be unambiguously restored with some reservations. The only exception is the edge of the image in the radius of the blur – there is no full restoration. The main way to restore image clarity is to process the observed image with an inverse filter [Sergienko, 2002]. The transfer function of the inverse filter is determined from the relation:

$$FPD\ (z_1, z_2) \bullet FPD_{inv.}(z_1, z_2) = 1,$$

whence $FPD_{inv.}\ (z_1, z_2) = 1/\ FPD\ (z_1, z_2)$.

Methodology

The restored image is equal to the sum of the original image and the noise transmitted through the inverse filter. In the absence of noise, an accurate reconstruction by the inverse filter of the original image is achieved. When images are restored with an inverse filter, edge effects arise, which manifest themselves as oscillating noise. To investigate the possibilities of reverse filtration (deconvolution), the program "Inversion of FPD.mcd" was developed [Dyakonov, 2007]. The results of the reverse filtration (scanning, deconvolution) of Mira-3 obtained by lenses with different FPD (a = 1, 10 and 100) in the absence of noise and identity of FPD in convolution and deconvolution are shown in Fig. Virtually achieved an ideal recovery, which does not depend on the size of the Airy spot.

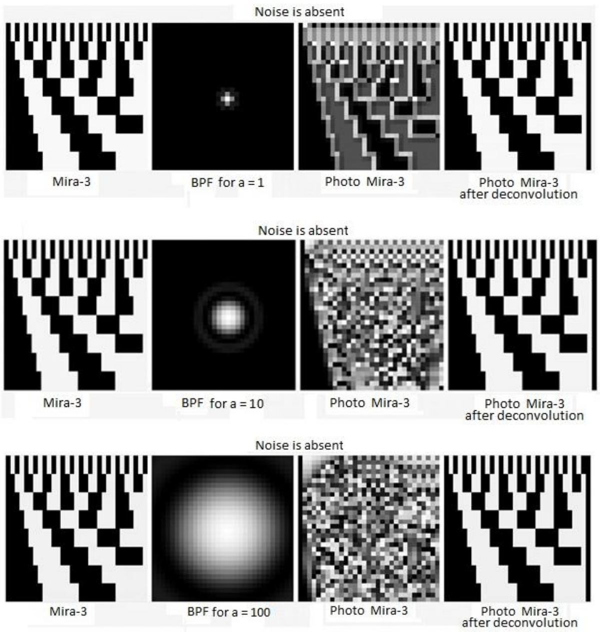


Fig. 4. Results of reverse filtration

About the effect of noise

Most often, the effect of noise in inverse filtering is considered regardless of the location of its influence [Soifer and others, 2002]. However, two options are possible with different results.

Option 1. Noisy world (or real object). In general, this option seems trivial. However, in the infrared range, photographs of one object at different times may have different noise components. As shown in Fig. 5, noise is perceived by the lens as an element of the original image and does not affect the quality of inverse filtering.

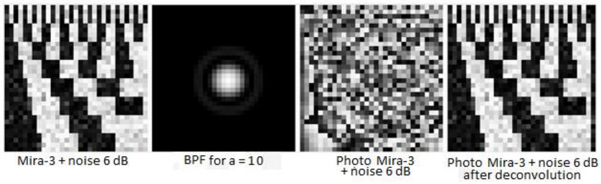


Fig. 5. Effect of noise on inverse filtering

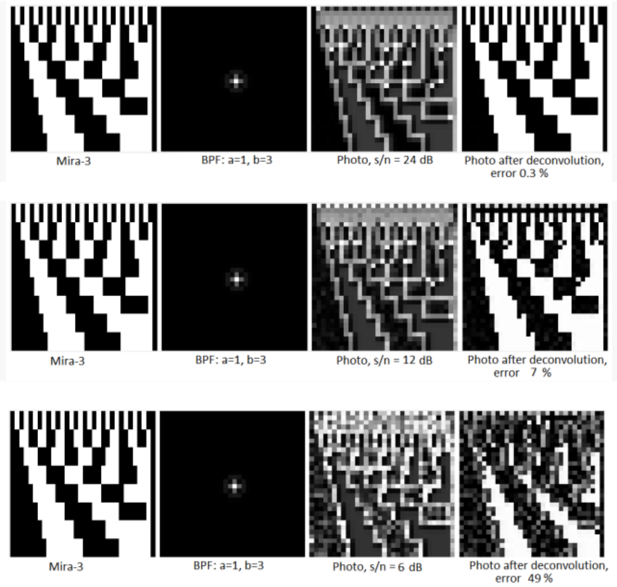


Fig. 6. Transmitting images over a noisy channel

Option 2. Noise is added to the image that is formed by the lens. Such a case is possible, for example, when the image from the receiving IR matrix is transmitted over a noisy communication channel for further processing by an inverse filter. As shown in Fig. 6, in this case it is not possible in this case, to restore the original image without distortion.

As shown in Fig. 7, the amount of distortion in this case depends on the size of the FPD.

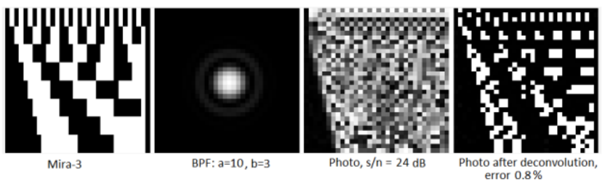


Fig. 7. The amount of distortion depending on the size of the FPD

Impact of inaccurate determination of FPD

Analytic (calculated) values of the FPD may be small, but they will still differ from the real ones. The difference between them is generally unknown [Prudyus Ivan. 2015} Therefore, before proceeding to deconvolution with real FPD, it is important to first estimate the permissible error between the FPD in the convolution (which is performed by the objective) and the FPD used in deconvolution. It is practically impossible to perform experimentally. Digital model of the FPD lens [Soifer, 2000] allows one to do this quite simply. To do this, we used a snapshot of Mira-2 of the objective model with a PSF at a = 1 and y = 1 (convolution), and deconvolution was performed with objectives with a FPD at a = 1–5 and y = 1. The quality of processing can be estimated visually and quantitatively. For this purpose, the relative error Δ% between the FPD used in the convolution and the FPD in deconvolution (FPD-0 and FPD-1, respectively) were calculated [Pereslavtseva et al., 2012]. The results are shown in Fig. 8.

In addition, the relative error μ% between Mira-2 and the image after deconvolution was calculated in parallel, as well as the mutual correlation coefficient Kr between them. Even with very small differences between FPD in convolution and deconvolution (which practically do not differ visually), the error grows rapidly. True, the cross-correlation coefficient falls off slowly. The fact is that even with a sufficiently large discrepancy between the FPD, the main details of Mira-2 can still be distinguished.

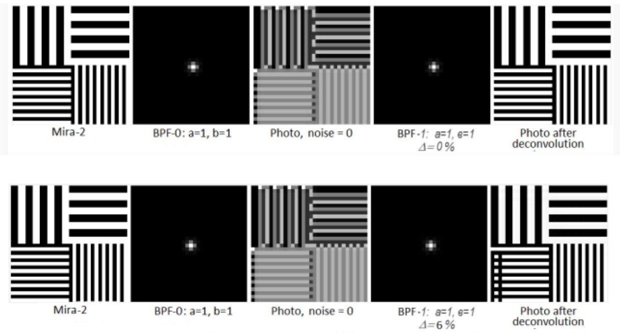


Fig. 8. Quality of processing of images Mira 2 depending on FPD

Result

To check the deconvolution of real images of thermal measures, two frames with more or less visually noticeable details were used: IR1_P15_32 and IR_P0,8_32. Deconvolution was carried out by the model of FPD with parameters a = 1 and y = 1.

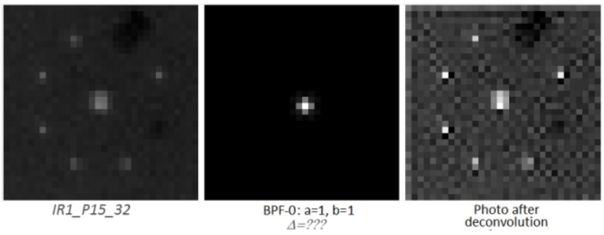


Fig. 9. Result of block frame

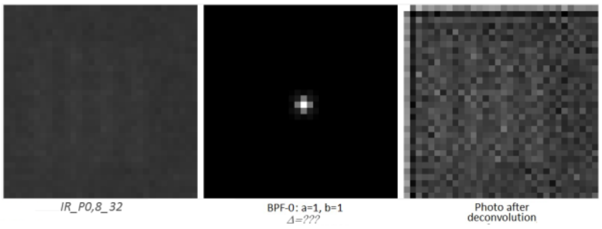


Fig. 10. Blurring the boundaries using the inverse filtering method

The results can only be judged visually. As can be seen from Fig. 9, the central the area of the IR1_P15_32 frame to deconvolution had a size of 4 × 4 pixels, and after – 3 × 3 pixels. Although the parameters of the model of PSF are chosen almost arbitrarily, but there is still some progress. It is difficult to make any conclusion about the result of IR_P0,8_32 frame processing. First, the contrast of the original frame is very small and, secondly, there are no clearly defined details for comparison in the frame. In addition the explicit blurring of the boundaries on this frame of the processed image, as mentioned earlier, as a drawback, which is inherent in the method-using reverse filtration [Krylov and others, 2014]. As shown in Fig. 10.

Scientific novelty and practical importance

The developed algorithm of reverse filtration (deconvolution) together with other methods (for example, sub-pixel processing) can be successfully used for processing IR images obtained as a result of remote monitoring of thermal objects. The deconvolution method allows to overcome the limitations on the resolution imposed by the optical system in the infrared range. This leads, in the absence of noise, to an accurate reproduction of the input image of the thermal object, regardless of the diameter of the light spot. The difference in the values of the FPD optics and the PSF model, which were used in the implementation of convolution and deconvolution programs, is of decisive importance. Especially important are the results of the operation of the method of reverse filtration under the conditions of noise on the thermal image and in the data transmission channel. The value of the signal-to-noise ratio at which the distortions are considered as insignificant is determined. At the same time, as the studies show, the magnitude of the photoluminescence spot of the objective is important. The question of application of the proposed method of reverse filtration in the case of uncertainty of lens data, which was used in thermal monitoring, is often encountered in the practice of processing thermal imagery available to the user. All the results obtained are verified on imitation models, which is the additional novelty and practical significance of the results obtained.

Conclusions

The method of reverse filtering allows to overcome the limitations on the resolution imposed by the optical system in the infrared range. In the absence of noise, an accurate reconstruction by the inverse filter of the original image is achieved. With a signal to noise ratio of less than 6 dB, the recovery quality is not necessarily high enough. The authors consider it promising to use this method to improve the quality of thermal images for monitoring objects in combination with their subpixel processing.

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ВИКОРИСТАННЯ МЕТОДУ ЗВОРОТНОЇ ФІЛЬТРАЦІЇ ДЛЯ ПІДВИЩЕННЯ РОЗДІЛЬНОЇ ЗДАТНОСТІ ІЧ-ЗНІМКІВ

Метою роботи є підвищення роздільної здатності ІЧ-знимків, одержаних у результаті моніторингу теплових об’єктів. **Методика**. Відомо, що жодна оптична система не може дати на ПЗЗ-матриці точкове зображення теплового об’єкта. Замість цього, формується дифракційне зображення плями, що призводить до значного погіршення якості теплового зображення. Зменшити вплив дифракції – це нагальне завдання системи формування та оброблення корисного сигналу. Для досягнення цієї мети запропоновано використання методу зворотної фільтрації, що дозволяє, знаючи функцію розсіювання точки (ФРТ) оптичної системи, обумовленої явищем дифракції, значно зменшити її вплив на якість одержаного теплового зображення. У системі оптика –комп’ютер оптичне зображення проектується на ПЗЗ-матрицю, де ФРТ представлено вже в цифровій формі. Метод заснований на зворотній фільтрації [Рабинер и другие, 1978]. Вважається, що розмиття – це необоротна операція і інформація безповоротно втрачається, тому що кожен піксель перетворюється на пляму, – все змішується. **Результати**. Показано, що вся інформація просто перерозподіляється відповідно до ФРТ і може бути однозначно відновлена з деякими застереженнями. Запропонована методика використання алгоритму зворотної фільтрації дає змогу подолати обмеження, які накладаються оптичною системою. **Наукова новизна.** Автори пропонують для визначення впливу величин ФРТ на роздільну здатність системи моніторингу використати спеціально розроблені цифрові міри та програму двумірної згортки (конволюції) цих зображень з ФРТ. **Практична значущість.** Розроблено алгоритм зворотної фільтрації (деконволюції) разом з іншими методами (наприклад, субпіксельної обробки) можна з успіхом використати під час оброблення ІЧ-знимків, одержаних у результаті дистанційного моніторингу теплових об’єктів. Метод деконволюції дає змогу подолати обмеження на роздільну здатність, які накладаються оптичною системою в ІЧ-діапазоні. Це призводить, за відсутності шуму, до точного відтворення вхідного зображення теплового об’єкта, незалежно від діаметру світової плями. Визначальне значення, має відмінність значень ФРТ оптики та ФРТ моделі, які використовувались під час реалізації програм конволюції та деконволюції. Особливо важливі результати дії методу зворотньої фільтрації в умовах дії шумів на тепловому зображенні і в каналі передачі даних. Визначена величина відношення сигнал / шум, за якого спотворення рахуються, як незначні. Водночас має значення, як показують дослідження, величина плями ФРТоб’єктива. Розглянуте питання застосування запропонованого методу зворотної фільтрації у разі невизначеності даних об’єктиву, який використовувався під час теплового моніторингу, що часто трапляється в практиці оброблення теплових знімків, наявних у користувача. Усі отримані результати перевірені на імітаційних моделях, в чому і полягає додаткова новизна та практична значущість отриманих результатів.

Ключові слова: роздільна здатність; об’єктив; функція розсіювання точки; модель; конволюція; деконволюція.

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