DARK CURRENT ELIMINATION IN CHARGED COUPLE DEVICES

L. Kňazovická, J. Švihlík

Department of Computing and Control Engineering, ICT Prague

Abstract

Charged Couple Devices can be found all around us. They are used in astronomy as a part of telescopes since 80`s of 20th century. In astronomical images can be found special type of noise called Dark Current. It`s necessary to remove this type of noise from images, that's the reason why usage of several basic statistic and filtering method for dark current eliminations have been studied. Applied methods must not damage or remove important objects (stars) in pictures. Results of all used methods are compared from visual point of view and also by method called Aperture photometry.

1. Introduction

Astronomical images are taken with long exposure times, when useful signal on CCDs is generated by photons incident onto photosensitive area. Thermal charge is also generated, in picture is it shown like noise called dark current. Rate of image contamination by noise has a direct proportion to the exposure time. Dark current can be generated in standard conditions like dark room with normal temperature in a few seconds. Dark current can be described with equation

$$I_d = A.e^{\frac{B}{kT}} \quad , \qquad (1)$$

where *A*, *B* are materials constants, *T* is a temperature in Kelvin and *k* is a Boltzmann constant ($1,38.10^{-23}$ J/K).

From mathematical point of view, Dark Current can't be describe as random quantity with normal (Gaussian) probability distribution, that's the reason why a lot of methods known for image denoising can't be used for elimination, e.g. thresholding [1].

Table 1: REVIEW OF SOME CHOSEN PARAMETERS OF USED ASTRONOMICAL IMAGE

	3m42-d03.sbg.dat
Bit Depth	16
Dimensions [px]	1536 x 1024
Exposure time [s]	60
CCD`s temperature [°C]	0,19
Ambient temperature [°C]	26,03

Dark current can be removed from images with method, where more images of same scene is needed. Dark frame is an image, which mapped dark current position in exposed image. It`s made at the same conditions as noisy frame (exposed image with presence of dark current), but objective is closed. Flat field is a visualization of system optical path – telescope – filters - camera. It mapped sensibility of each CCDs pixel on light, vignette and chip impurity. This type of image is made by scan of white area which is lightning uniformly. By dark frame and flat field is possible to remove dark current from light frame. Disadvantage of this method is necessity of presence of all 3 types of images. But mostly only noisy or noisy and dark frame are available, so it`s necessary to remove dark current with another methods. All methods have been applied in MATLAB.

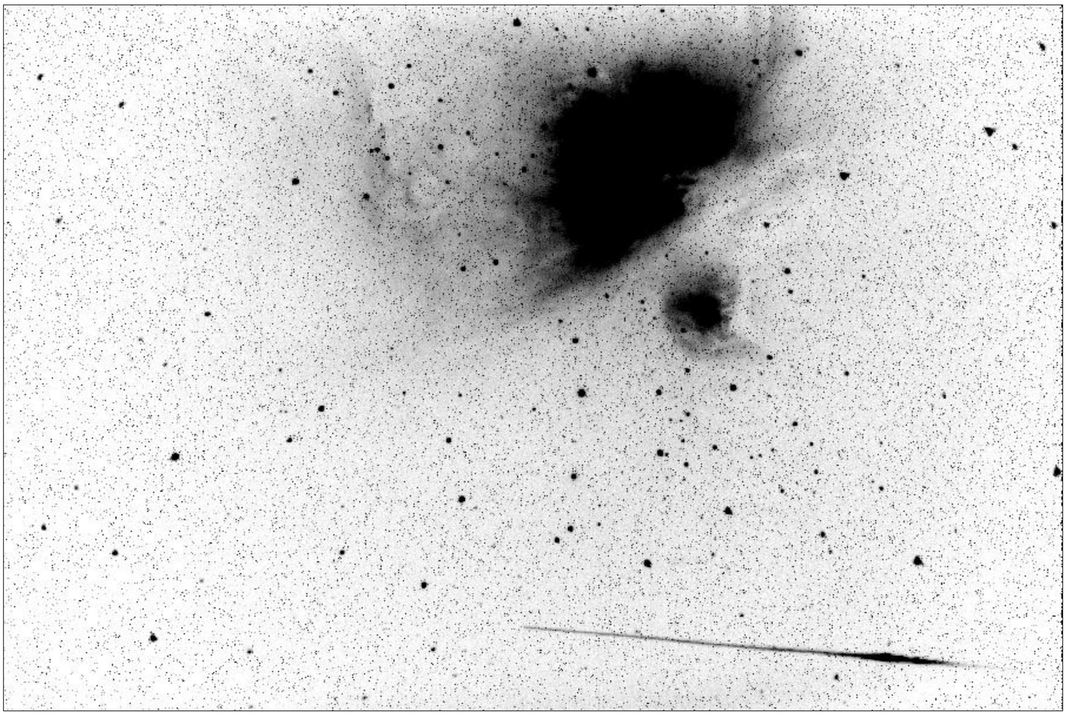

Figure 1: Astronomical image with Dark current presence

2. Applied Methods

Median filter belongs to order-statistic filters used for image noise elimination [2, 3]. It`s response is based on replacement of value of the pixel by the median of the gray levels in the neighborhood of that pixel:

$$\hat{f}(x,y) = \text{median}\{g(s,t)\}, (s,t) \epsilon S_{x,y} \tag{2}$$

The original value of the pixel is included in the computation of the median. Median filter provide excellent noise-reduction abilities with considerably less blurring than linear smoothing filters of similar size. They are effective in the presence of impulse noise. But median filter isn`t filter ideal, because after its usage some important details can be removed.

Wiener filtering considers images and noise as a random process [2, 4]. Target is to find an estimate $\hat{f}$ of the uncorrupted image *f*. The mean square error between estimate and uncorrupted image is minimized and is given by

$$e^2 = E\left\{\left(f - \hat{f}\right)^2\right\} \tag{3}$$

where $E\{\quad\}$ is the expected value of the argument. It`s supposed that the noise and the image are uncorrelated, one of the signals has zero mean, and the gray level in the estimate are a linear function of the levels in the degraded image. Minimum of the error function in eq. (3) is given in the frequency domain by the expression

$$
\begin{aligned}
\hat{F}(u,v) &= \left[\frac{H*(u,v)S_f(u,v)}{S_f(u,v)|H(u,v)|^2 + S_\eta(u,v)} \right] G(u,v) \\
&= \left[\frac{H*(u,v)}{|H(u,v)|^2 + S_\eta(u,v)/S_f(u,v)} \right] G(u,v) \qquad (4) \\
&= \left[\frac{1}{H(u,v)} \frac{|H(u,v)|^2}{|H(u,v)|^2 + S_\eta(u,v)/S_f(u,v)} \right] G(u,v)
\end{aligned}
$$

where we used the fact that the product of a complex quantity with its conjugate is equal to the magnitude of the complex quantity squared. This result is known as the Wiener filter. The filter, which consists of the terms inside brackets, also is commonly referred to as the minimum mean square error filter or the least square error filter. The terms in eq. (4) are as follows:

$H(u,v)$ … transform of degradation function

$H*(u,v)$ … complex conjugate of $H(u,v)$

$|H(u,v)|^2 = H*(u,v)H(u,v)$

$S_\eta(u,v) = |N(u,v)|^2$ … power spectrum of the noise

$S_f(u,v) = |F(u,v)|^2$ … power spectrum of the undegraded image

$G(u,v)$ … transform of the degraded image.

The restored image in the spatial domain is given by the inverse Fourier transform of the frequency-domain estimate of $\hat{F}(u,v)$.

One of the input parameter for this method is noise level of noisy image. This level has been calculated as difference of power spectrum of noise and undegraded image.

Filtering in the Frequency Domain [2, 5] is quite simple method and consists of a few steps:

1. Transformation of noisy image by Discrete Fourier Transform (DFT) into frequency domain, result of this operation is an image spectrum in frequency domain $F(u, v)$.
2. $F(u, v)$ is multiplied by a filter function $H(u, v)$.
3. Inverse DFT of the result in (2.) is computed.

$H(u, v)$ is called a filter (or filter transfer function), because it suppresses certain frequencies in the transform while others leave unchanged.

Filtration is made by low-pass filters, which reduces high frequencies, lower frequencies are saved. For Dark Current eliminations have been used filters with rectangle and circle shape. As can be shown on final images, this method can be used for noise elimination, even though in the background are presented residual fragments of noise. Next think which have to be considered is that if only very low frequencies are released, some information can be loosed and image can be blurred.

3. Performance evaluation

Well-known methods for results examination, like Mean Square Error or Root Mean Square Error aren't appropriate for Dark Current elimination from astronomical images. To get some objective criterion is used method called *Aperture photometry* [6]. This method consists in sum of signal source in artificial aperture. It's quite easy because there is no necessity of usage complicated mathematical procedures and it can be applied on any shape of object.

Very important term for this part of work is *magnitude*. It's photometric quantity used in astronomy which refers to the logarithmic measure of the brightness of an object. This value presents apparent brightness of the star. Value of the magnitude is independent from real dimensions of the object.

Principles of this method can be described in a few steps:

1. Selection of same object in noisy, noise free image and image after application described method
2. In noise-free image is reference object selected.
3. In the others images are found same objects as in the noise-free image.
4. Magnitude of reference object is set to value 10
5. Comparison of objects magnitudes

Method can be considered as successful if magnitude in noise-free image and image after some method application are very similar. In Fig. 2 is shown principle of aperture photometry.

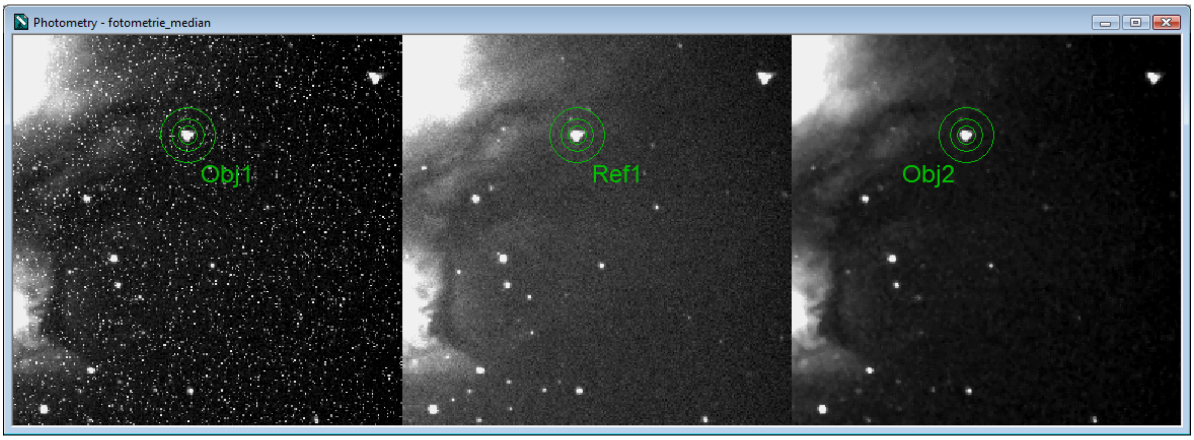

Figure 2: Aperture photometry – chosen objects from image cuts, left – noisy image, middle – noisy free image with reference object (Ref 1), right – image after Median filter application

4. Results

From visual point of view, *median filter* can be considered as very effective method for Dark current elimination (Fig. 3), because from noisy image have been noise successfully removed. All images are shown in inverse visualization for better presentation of results.

Result of application *Wiener filter* onto noisy picture is shown in Fig. 4. From visual point of view this method can be consider also as successful, even though near stars are presented some fragments which belongs to Dark Current.

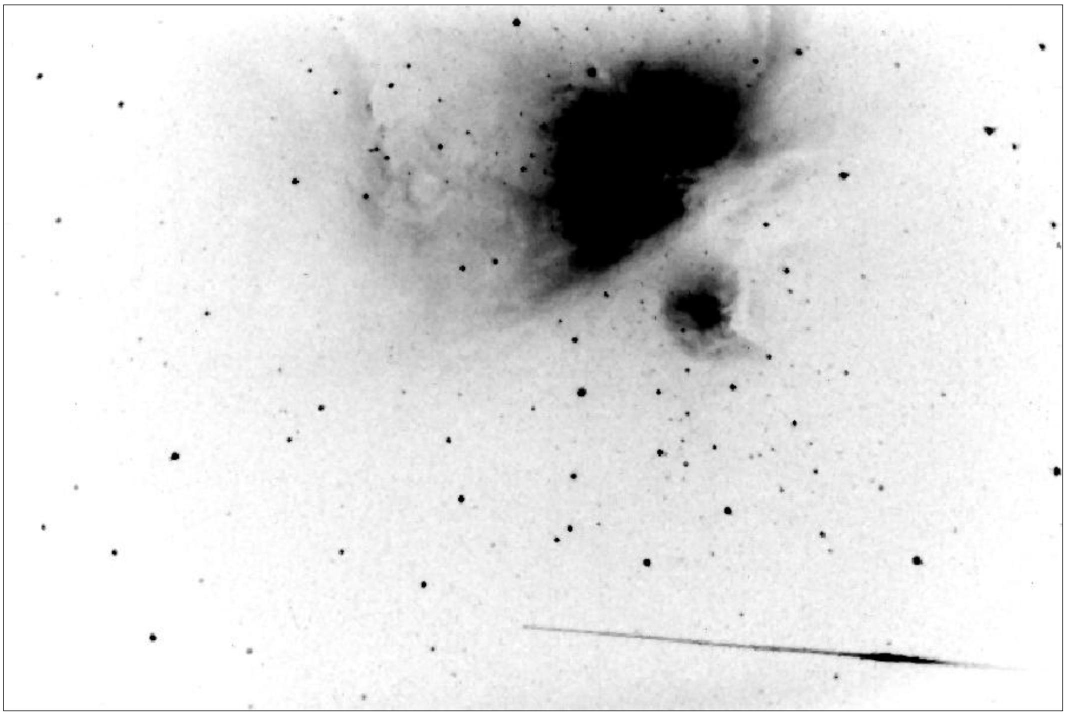

Figure 3: Result after median filter application

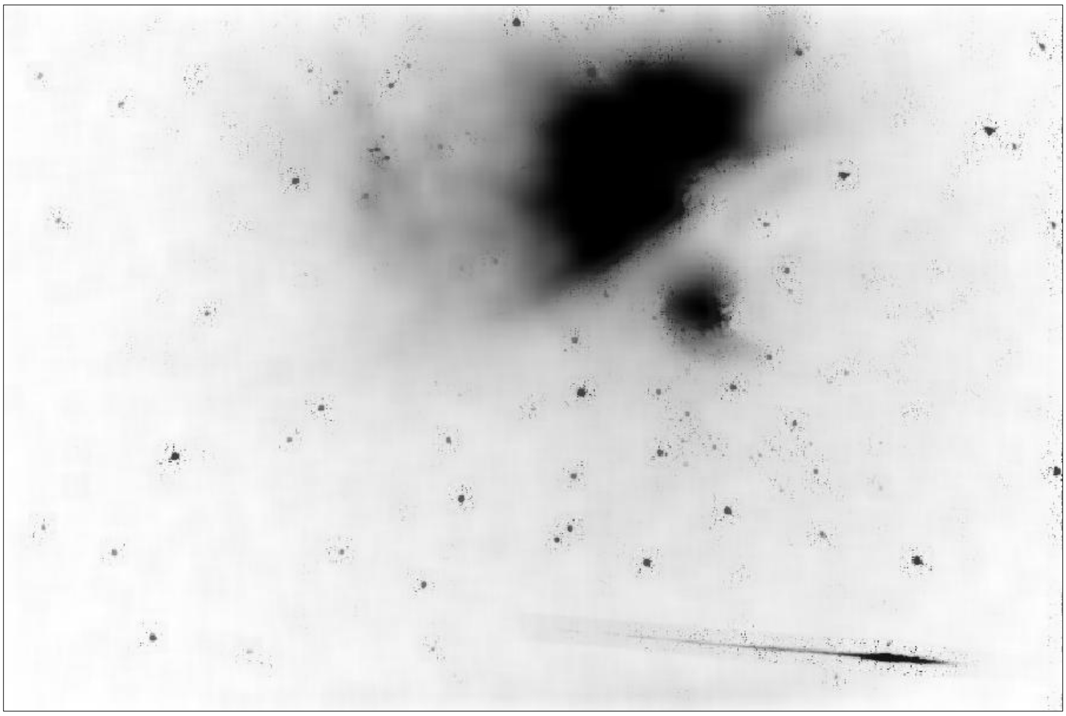

Figure 4: Result after Wiener filter application

Results of application *Filtering in Frequency Domain* are shown in Fig. 5. From visual point of view can be this method classified either as successful, Dark Current is suppressed, even in the background are visible some fragments which belongs to the noise.

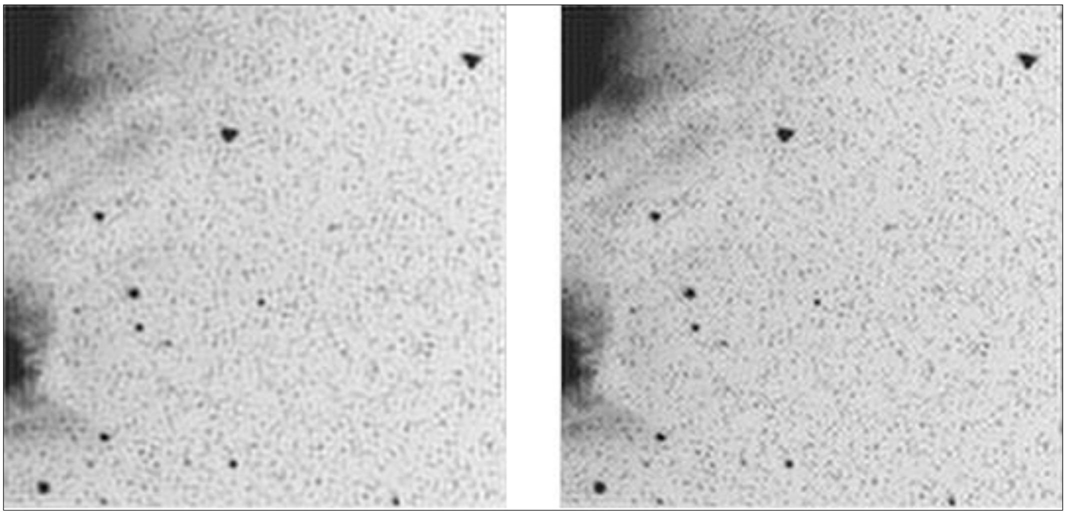

Figure 5: Results after Filtering in Frequency Domain, left – rectangle shape of filter, right – circle shape of filter

When results are evaluated by *Aperture photometry*, it can be said, that successful methods for Dark Current elimination are *Median filter* and *Filtering in Frequency Domain*. Values of object magnitudes in reconstructed images are similar to reference magnitude. Application of Wiener filter can't be considering as successful, because magnitude in reference image is higher than value of reference magnitude. All results are summarized in Table 2.

Table 2: COMPARISON OF MAGNITUDES

object	magnitude
Reference – noise-free image	10,000
Noisy image	9,903
Median filter	9,954
Wiener filter	10,243
Filtering in Frequency domain – rectangle shape	9,986
Filtering in Frequency domain – circle shape	9,988

5. Conclusion

The different methods for Dark Current eliminations from astronomical images have been studied in this work. Dark Current is a noise which can't be assumed as Gaussian, so there is no possibility to use e.g. thresholding for image denoising. From visual point of view shows all applied methods as successful, all methods prove ability to remove this kind of noise. Evaluation by Aperture photometry gives us little bit different results. Median filter and Filtering in Frequency Domain we can consider also as successful, because by magnitude comparison we obtain quite similar values. But value of magnitude obtain after application of Wiener filter is higher than reference magnitude, so this method can't be consider as successful.

6. References

[1] Pizurica, A., *Image Denoising Using Wavelets and Spatial Context Modeling*, Universiteit GENT, 2002

[2] Gonzalez, R. C.; Woods, R. E. *Digital Image Processing*, 2nd edition; Prentice-Hall: Upper Saddle River, New Jersey 07458, 2002, ISBN 0-201-18075-8.

[3] Štork, M., Mediánové filtry a jejich použití při filtraci impulsních šumů, http://vyuka.fel.zcu.cz/kae/+eln/Median02.pdf

[4] Uhlíř, J., Sovka, P., *Číslicové zpracování signálů*, 2. vydání, vydavatelství ČVUT, Praha 2002, ISBN 80-01-02613-2

[5] http://uprt.vscht.cz/prochazka/pedag/DSPc.htm, January 2010

[6] Romanishin, W., *An Introduction to Astronomical Photometry Using CCDs*, University of Oklahoma, October 2006, http://observatory.ou.edu

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Lenka Kňazovická
Department of Computing and Control Engineering, ICT Prague, Lenka.Knazovicka@vscht.cz

Jan Švihlík
Department of Computing and Control Engineering, ICT Prague, Jan.Svihlik@vscht.cz