

DepAstroCCD AN ORIGINAL ASTROMETRIC TOOL

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SUMMARY: A complex software for preparation and treatment of astro photographic plates and double-star observations recorded with CCD cameras is developed. The preparation interface contains a catalogue base for the choice of observation objects and an interface for bringing into accordance the telescope and CCD camera performance with the assumptions of the postprocessor interface. The processing is based on the original development of image gradient removing software and classical FFT method and autocorrelation. The software has been tested on several theoretical and real images of double stars.

Key words. Techniques: image processing - **Astrometry - binaries:** visual

1. INTRODUCTION

The great era of astrometry is history, but it received now a fresh impetus from the precise satellite measurements of celestial angles and the products of the new technology era (CCDs, fast computers, space missions, ...). The aim of this paper is to give a first attempt to overview the status of the use of CCDs in astrometry along with some of the problems, one encounters when using this technique. Since their introduction in astronomy some 25 years ago, Charge Coupled Devices (CCDs) have had a large variety of applications as two-dimensional detectors in astrometry.

The direct access to the machine readable data from CCDs have led to a replacement of photographic plates by CCDs for many astrometric measurements (e.g. discovering new bodies in solar system, positioning of minor planets, parallaxes and proper motions of single stars and double stars, parametrizing double and multiple stars and so on. . .).

We hope to cover some questions of special interest and to yield some detailed arguments, in order to give support to observers just starting to observe double stars with their CCDs.

We investigate how accurately the position of a celestial body with respect to background field of image can be determined using CCD data position. The first step was to decide when the image is ready to be used in the further treatment. We concentrate our attention to the gradient removing process, the automatization of selection of objects to be observed, and the reduction of observations.

2. GRADIENT REMOVING

The first kinds of gradients are linear gradients that fade from one side of the image to the opposite one. Linear gradients can be at any angle, both horizontal and vertical. Linear gradients are fixed by specifying the amount of the gradient, and its angle. The second kind of gradients are radial

gradients that have a central hot spot that fades to the darker shades away from the center.

We created the gradient removing semi-automatic software. This software allows us to remove the linear gradients in the background level with some degree of precision. The function of a linear gradient is discovered by use of the least-square method and on that basis we filtrate the image. We find that this tool enables to measure a linear gradient, determine its direction, and then to remove it clearly.

There are various settings in the software that determine how a gradient gets removed. The following list provides a quickstart set of definitions.

Gradient amount: For example, if the left edge of the image has a brightness at N ADU, and the right edge is at M , then the amount of the gradient is $N - M = \Delta G$. The gradient is the gradient amount in ADU intensity per distance unit l in mm or pixels

$$\Delta G/l.$$

The gradient angle applies to linear gradients only. The angle values increase clockwise. The basic direction of the gradient is arbitrary, but we suggest to choose directions towards the longer side of image. In our menu, you have possibility to choose directions in both equatorial and alt-azimuthal systems (Fig. 1).

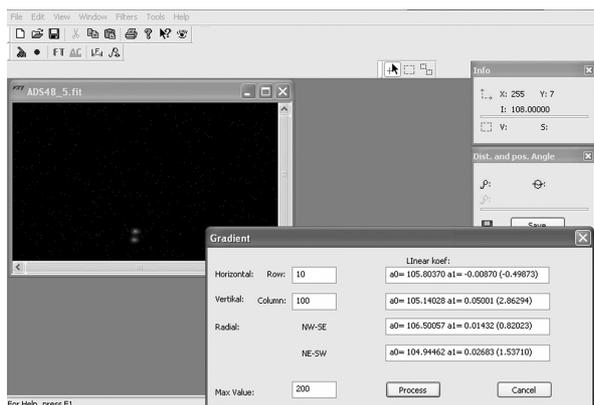


Fig. 1. Menu for gradient removing.

3. SEMI-AUTOMATIC PROCESSING OF THE OBSERVATIONAL DATA

Like many other applications at various observatories, some applications of CCDs in astrometry related to the projects of double stars orbit determination, are realized at Belgrade observatory (Popović et al. 1996, Pavlović et al. 1996). In particular, we are interested in using this software for the purpose of treating the already digitalized CCD data for all astrophotographic plates (the oldest, from early 1930's, to the newest, late 1980's), as the first epoch material to study the positions and masses of asteroids and their orbital characteristics (Olević et al. 1988). Moreover, another benefit of this activity can

be the identification of many of the photographed stars and measurement of their coordinates.

At this stage the developed software has three parts: the first one is software for choosing (defining) general astronomical conditions – sidereal time based on synchronization of computer clock with UTC via INTERNET, period of darkness (time interval among twilights), Moon phases and Moon elongation (see Figs. 1 and 2); the second one is a software for choosing objects to observe and internet catalog selection, with a full list of objects observable in the period described in the previous section (see example in Figs. 3 and 4); and, finally, the third one, is "our" software tool for image processing – preprocessing with gradient removing and instrumental parameters calculating and processing by use of slightly modified wide applicable FF and AC transformation (see Figs. 5 and 6).

For the purpose of digitalizing astrophotographic plates only one part is used, that concerning the linear gradient removal. The user interface is originally developed by I. Stojanović and P. Glišović under the supervision of R. Pavlović and S. Šegan.

4. IMAGE PREPROCESSING – GRADIENT REMOVING

In the main menu **Option-Tools** you can find the way to remove the linear gradient (see Fig. 1). As it is presented in Figs. 2. and 3, by moving the cursor over the image you can show the pixel intensity and its position: for example, near the object (double star ADS48) it is about 93 ADU and "over" it the value is about 785 ADU.

The calculated parameters are simple for application and as a control parameter you can find the inclination of the straight line (tan of angle) in brackets. Subtracting such a gradient is easy.

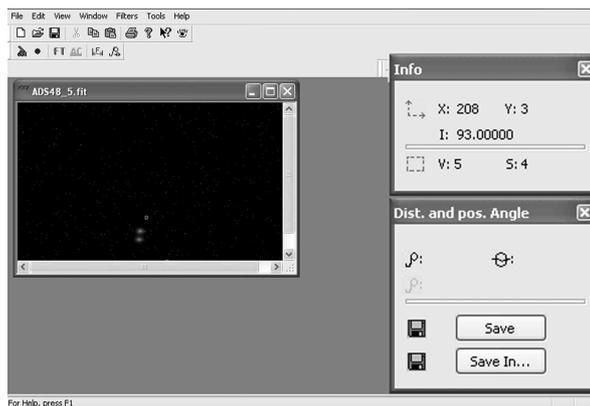


Fig. 2. Menu for showing pixel intensity and its position (near the object it is about 93 ADU).

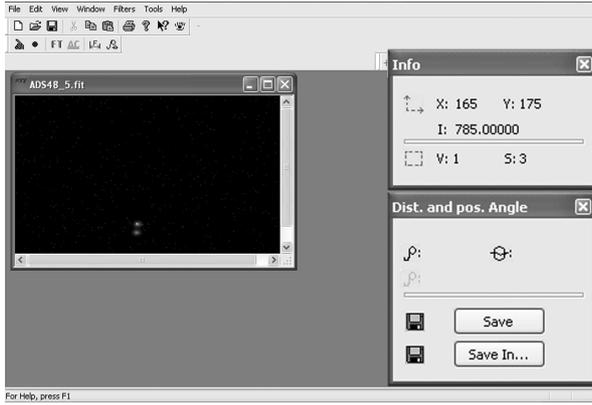


Fig. 3. Menu for showing pixel intensity and its position ("over" the object it is about 785 ADU).

5. IMAGE PROCESSING – REDUCTION OF OBSERVATIONS

The astronomical sky is two-dimensional distribution of intensity of electromagnetic radiation. If we define the specific intensity $I_s(\theta)$ from angular direction $\theta(\alpha, \delta)$ then the measured integrated spectral illumination is ¹

$$I(\rho, \alpha, \delta) = \int_{\Delta S} I_s(\theta) d\theta \equiv \text{coeff} \prod_{j=1}^m f_{\lambda}^j \int_{\Delta V} E(\lambda) d\lambda. \quad (1)$$

The image process starts from the object $E(\lambda)$ and produces the image $I(\rho, \theta)$ via degraded transformations like diffraction, noise and distortions (small factors f_{λ}^j). Conversely, the restoration process recovers an object as the estimation of the object $E I(\lambda)$. The *coeff* in (1) is the corrective factor among $E(\lambda)$ and $E I(\lambda)$.

An image may be studied in the Fourier domain. Let us define the Fourier transform of $F(x)$ by

$$FT(s) = \int_{-\infty}^{+\infty} F(x) e^{-2i\pi s x} dx, \quad (2)$$

and extend to two dimensions

$$FT(S) = \int \int F(\theta) e^{-2i\pi S \theta} d\theta. \quad (3)$$

We define $IT(S)$ as the complex image spectrum and S as frequency ν .

In (3) the formula for FT is given in the general form, and we now proceed to showing how FT can be used for practical problems. A digital picture in the output device with its structure represents a grid of pixels in which each pixel is assigned a number of bits. Each pixel represents the unit of fictive

coordinate system depending on the device. If we assign a value to a pixel, i.e. the pixel intensity, each of digital pictures can be represented by a function $f: \mathfrak{R}^2 \rightarrow \mathfrak{R}$.

All the operations on a digital picture can be transferred into a space of matrix and algebra operations on it. The elements of the matrix are pixel intensities.

Now our formulae for FT in space \mathfrak{R} can be written in the following form:

$$R(u, v) = \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \cos\left(\frac{xu + yv}{N^2}\right), \quad (4)$$

$$I(u, v) = \sum_{x=0}^{N-1} \sum_{y=0}^{N-1} f(x, y) \sin\left(\frac{xu + yv}{N^2}\right), \quad (5)$$

$$A^2(u, v) = R^2(u, v) + I^2(u, v). \quad (6)$$

In these formulae, $u, v = 0, \dots, N-1$ are the test frequencies along the, respectively, x -axis the y -axis, $R(u, v)$ and $I(u, v)$ are, respectively, the real and the imaginary parts of the complex form of FT, A – is the amplitude, $f(x, y)$ – is the pixel intensity of a digital picture, where x and y denote the numbers of rows and columns of the digital picture, respectively.

Also we can define the autocorrelation function:

$$\begin{aligned} AC &= F(u, v) \cdot \bar{F}(u, v) = \\ &= (R(u, v) - iI(u, v)) \cdot (R(u, v) + iI(u, v)) = \\ &= R^2(u, v) + I^2(u, v) = A^2(u, v). \end{aligned} \quad (7)$$

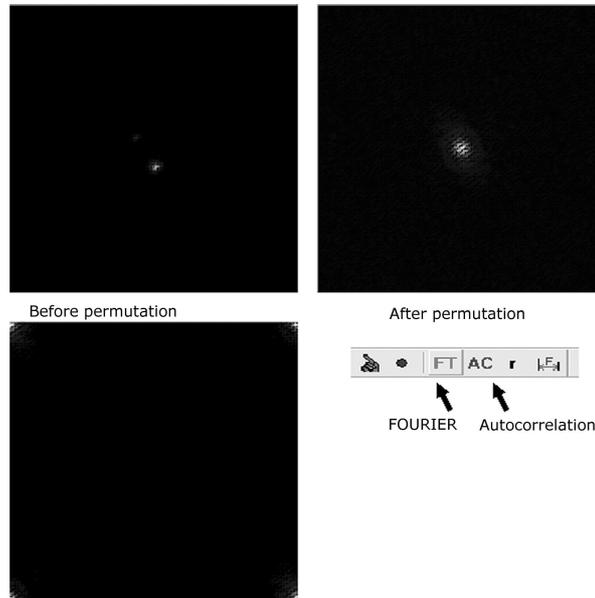


Fig. 4. Digital pictures before FT and after FT and AC.

¹This is the generalized expression in the field of electromagnetic waves, based on experimental space-time modelling!

After calculating the Fourier transforms and the autocorrelation function we start the calculation of the separation and position angle for a double star. Having in mind that the function $f : R^2 \rightarrow R$ can have more than one maximum for the reference points of the secondary peaks (as in SINC function) we choose the center of their gravities. Their values are calculated in a similar way as in astronomy: one calculates the baricenter:

$$\vec{C} = \sum_i (AC)_i \cdot \vec{r}_i, \quad (8)$$

or coordinated,

$$C(x) = \sum_i AC(i, v) \cdot i \quad C(y) = \sum_j AC(u, j) \cdot j. \quad (9)$$

In these formulae $i, j = 1, \dots, n$ are, respectively, indices along the x - and y -axes, and AC is the autocorrelation function.

By determining $C_1(x_1, y_1)$ and $C_2(x_2, y_2)$, which is done in the programme automatically by selecting the secondary peaks (Fig. 6 further the text), it is easy to calculate the separation and the position angle,

$$\rho = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \quad \varphi = \arctan \frac{y_2 - y_1}{x_2 - x_1}, \quad (10)$$

where ρ is expressed in pixels. Bearing in mind the pixel dimension and focal length of the telescope F , for ρ (arc seconds) one obtains:

$$\rho'' = \frac{3600 \cdot 180}{\pi} \cdot \frac{\sqrt{(0.023 \cdot (x_2 - x_1))^2 + (0.027 \cdot (y_2 - y_1))^2}}{F}. \quad (11)$$

This initial work motivated us to study in more detail how accurately stellar positions could be measured as compared with to the older techniques. In an ideal world, for the photographic plates one would like to have a selection of background point sources as reference points. However, because of the small size of the view field registered with a CCD chip, the probability of having a sufficient number of reference points in that field of view is low (Olević *et al.* 1986). Hence, to derive the coordinates, we adopt this DepAstro CCD software to "observe" the plates themselves.

As a new example of the software possibilities in the case of an acquired double star image one can scan the following two images. The Table in Appendix I explains better the possibilities of our software as compared with the previous procedures for reduction of observations introduced by Popovic, Pavlovic, Zivkov for double stars ADS48 and ADS56. Our software DepAstro CCD gives a result for the separation of ADS48 $\rho = 5.''877$ which is nearest the catalogue value $\rho = 5.''976$ and this is a better result than the one given by the previous observations.

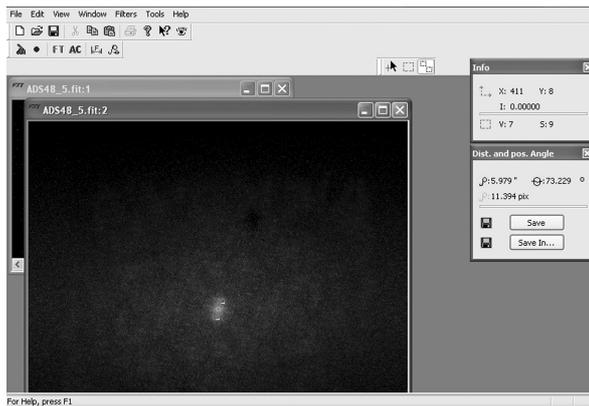


Fig. 5. Menu for calculating the distance ρ and orientation ϑ of the components of double stars.

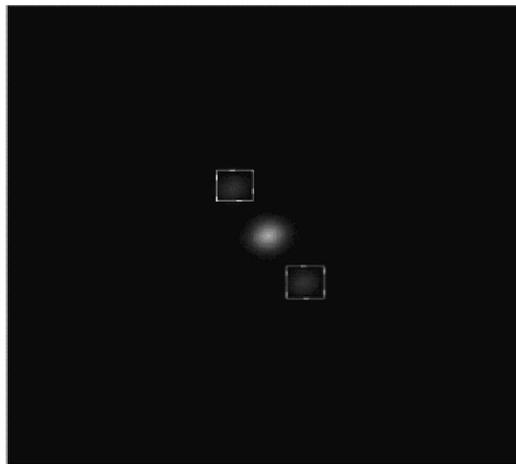


Fig. 6. Automatic selecting of the secondary peaks.

6. CONCLUSIONS

As we can see, a simple algorithm suffices for linear gradient removing in the case of astrometric CCDs imaging of the double stars.

The software tool for an automatic selection of objects to observe is user friendly and widely applicable. Two-dimensional discrete FFT accompanied with Auto-Correlation function, in the form described above, is very simple to explore in the case of double stars and in other cases, too. The source code is in the visual C++ and is obtainable under request.

Even with an unexperienced users, the results for the distance ρ and orientation ϑ of the components of double stars are in absolute agreement with those obtained by visual and photographic methods. The examples are given in Figs. 5 and 6.

This is an useful tool for discovering of some sources of errors in astrometric measurements, including astronomical seeing, exposure duration, geometry of reference stars in the field of view, type of reference catalogue and mode of observation.

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APPENDIX I –
TABLE OF COMPARISON

ADS	Epoch	ϑ_{eph}	ρ_{eph}	ρ_{CCD}	n_{exp}	Observer
ADS48	1994.796	179.°86	5."976	6."148	5	Popović
				6."152	5	Pavlović
				6."208	5	Živkov
				5."877	3	DepAstroCCD
ADS56	1994.785	147.°54	7."726	7."598	5	Popović
				7."770	4	Pavlović
				7."638	5	Živkov
				7."704	4	DepAstroCCD

DepAstroCCD

ЈЕДНА ОРИГИНАЛНА АСТРОМЕТРИЈСКА АЛАТКА

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Стручни рад

Дат је скуп програма сукцесивно примењивих за припрему и обраду старих астрографских снимака (фотоплоча) и нових ССД снимака двојних звезда. Припремни интерфејс садржи базу каталога за избор посматрачких објеката у складу са уграђеним инструмент-

ским перформансама и захтевима постпроцесирања. Дат је сопствени модул за уклањање градијента и модули за идентификацију параметара ликова помоћу FFT и аутокорелационе трансформације