International Journal of Electrical, Electronic and Communication Sciences
ISSN: 2517-9438
Vol:4, No:5, 2010

2D Image Processing for DSO Astrophotography

R. Suszynski, K. Wawryn and R. Wirski

***Abstract*—**The new concept of two–dimensional (2D) image processing implementation for auto-guiding system is shown in this paper. It is dedicated to astrophotography and operates with astronomy CCD guide cameras or with self-guided dual-detector CCD cameras and ST4 compatible equatorial mounts. This idea was verified by MATLAB model, which was used to test all procedures and data conversions. Next the circuit prototype was implemented at Altera MAX II CPLD device and tested for real astronomical object images. The digital processing speed of CPLD prototype board was sufficient for correct equatorial mount guiding in real-time system.

***Keywords*—**DSO astrophotography, image processing, two-dimensional convolution method, two-dimensional filtering.

I. INTRODUCTION

ASTRONOMY is getting more and more popular also with the amateur astronomers. The important field of their activity is astrophotography. Nowadays the widespread ability of equipment that produces amazing, high-quality results with reasonably at prices to many amateur astronomers. In order to produce images of deep sky objects, especially at focal lengths over 200 mm, it usually becomes necessary to guide the telescope during the image exposure. Even the finest, most expensive mounts are plagued with enough mechanical imperfection or alignment error to produce oblong stars. In the Figures 1 and 2 pictures of M109, a barred spiral galaxy in the constellation of Ursa Major are shown. The first one is made in condition of correct stars tracking by telescope drive. The stars are circle dots with magnitude proportional to relative brightness. However the second one shows telescope guiding inconsistent with sky revolution. Mowing of telescope in the way different to speed and direction of mowing sky, causes fuzzy stars image proportional to drive error. The photographed object – M109 galaxy is fuzzy too. Its image has lost details visible on the first picture. In the Figure 1 the six brightest stars are selected to the next image processing (the small square frame up right side of the M109 galaxy).

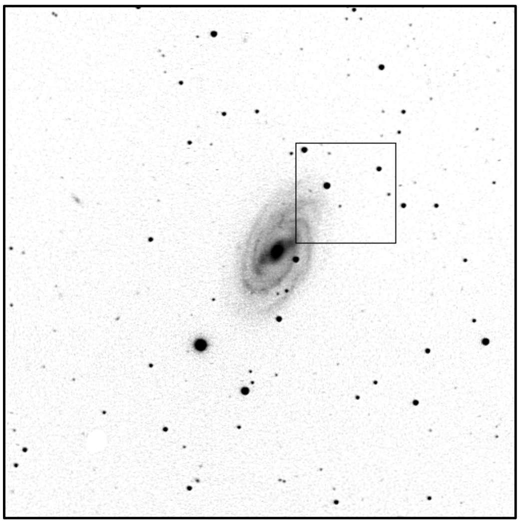

Fig. 1. Messier 109 (M109), a bared spiral galaxy in the constellation Ursa Major, picture with correct stars' tracking.
Refractor SW 80ED, 80mm/600mm, SBIG ST2000XM,
one exposition 300 s, photo: Robert Suszynski 09.05.2009.

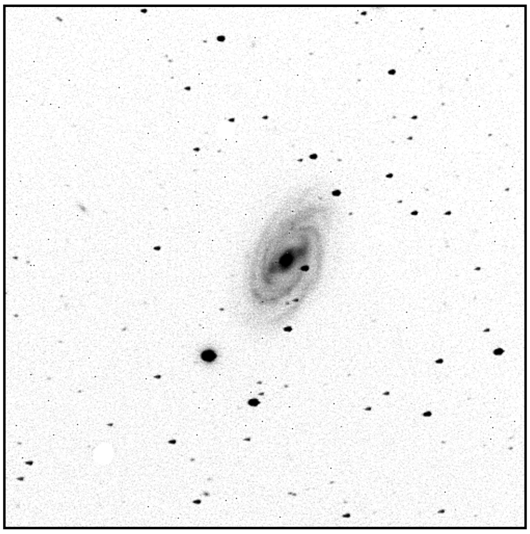

Fig. 2. M109 picture with driving inconsistent with sky revolution.
Refractor SW 80ED, 80mm/600mm, SBIG ST200XM,
one exposition 300 s, photo: Robert Suszynski 09.05.2009

R. S. Author is with the Faculty of Electronics and Information Science, Koszalin University of Technology, 75-453 Koszalin, Sniadeckich 2, Poland (corresponding author to provide phone: +48943478718; fax: 48943433479 e-mail: roberts@tu.koszalin.pl).

K. W. Author is with the Faculty of Electronics and Information Science, Koszalin University of Technology, 75-453 Koszalin, Sniadeckich 2, Poland (e-mail: wawryn@tu.koszalin.pl).

R. W. Author is with the Faculty of Electronics and Information Science, Koszalin University of Technology, 75-453 Koszalin, Sniadeckich 2, Poland (e-mail: wirski@op.pl).

Supported by the Polish Ministry of Science and Higher Education and Science under Grant Singapore/106/2007

II. AUTO-GUIDING SYSTEM

Originally, guiding was done with the photographer staring through an eyepiece at a guide star and manually correcting the movement of the scope to keep the guide star's position fixed. Within the last years manufacturers of astronomy equipment have developed and sold dedicated auto-guiding systems that have unchained the photographer from his eyepiece and increased the success rate achieved. These systems are very effective, but also relatively expensive. An alternative solution to such systems is using simply CCD guide camera interacting with PC computer. Unfortunately such systems have some disadvantages too. Observation place must be equipped with personal computer, dedicated software and additional power supply, which is expensive and inconvenient.

The main goal of the project described in this paper is to build dedicated auto-guiding system. It should use simply astro-camera to collect stars images and DSP system to filtering and processing these signals. Most of necessary circuits can be build using CPLD devices [1, 2]. This approach made it possible to build easy to use and not expensive auto-guiding system, which can be useful for long exposure Deep Sky Object (DSO) astrophotography.

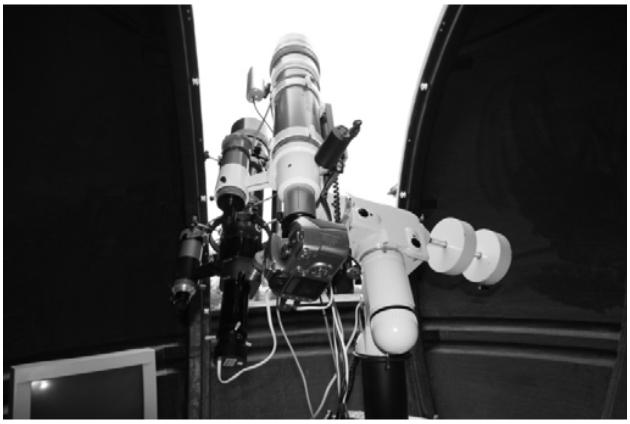

Fig. 3. A station for testing auto-guiding system.

Observation post which was use to test auto-guiding systems is shown in Figure 3. The lower telescope, Orion 80mm/600mm refractor with ALccd 5 camera works as guide star tracking system. The upper telescope, SkyWatcher 80ED 80mm/600mm refractor interacting with Canon 300D camera makes DSO pictures. Both of them are drove by SkyWatcher EQ6 PRO mount. It drives telescopes in both directions, under control guiding signal on ST4 compatible input.

Simply CCD astro-camera interacting with motorized telescope driver and auto-guiding system (computer PC or dedicated circuit) can be effective system for astronomical object tracking correction. CCD camera makes guide star's pictures repeatedly. Its position is detecting as co-ordinates of pixels with the biggest recorded brightness. In case of star drifting owing to tracking errors the star image will be recorded at different positions in next frame. Then auto-guiding system calculates changing of initial position and generates correction signals for drives and moves telescope. It should read star image, make data processing and calculate correction at less than 1 second.

III. DIGITAL METHOD FOR IMAGE CORRECTION AND STAR POSITION DETECTION

The images of stars in astrophotography are always deformed so they are recorded by more than one pixel of CCD matrix. The main reasons why it is happen are:

- a tracking errors for recorded object,
- mechanical vibration,
- optical systems defects,
- atmosphere turbulence.

Astrophotography by CCD cameras are applying digital signal processing to improve the recorded images. Wide group of methods are modifying pixel values to improve quality of visual images or correct reordered object parameters (such as: position, relative brightness, spectral profile). Usually in this methods new pixel value is calculated as weighted function of initial value of the pixel and its square surroundings [3, 4].

Before changing the guide stars' position calculation, the autoguider system makes digital processing of signal from CCD camera. It reduces noise signals and improves star position calculation. Next the new guide star position is calculated and compared with initial position. Estimated values for star moving are used to drive correction signals generation.

New efficient image processing algorithm using two–dimensional (2D) filtering and convolution methods to detect movement of recording images have been proposed and implemented.

The following 2D transfer function matrix

$$\boldsymbol{H}(z_h, z_v) = \begin{bmatrix} 1 & z_h^{-1} & z_h^{-2} \end{bmatrix} \begin{bmatrix} -1 & -1 & -1 \\ -1 & 9 & -1 \\ -1 & -1 & -1 \end{bmatrix} \begin{bmatrix} 1 \\ z_v^{-1} \\ z_v^{-2} \end{bmatrix} \tag{1}$$

has been used for preliminary filtering. The 2D transfer function has been decomposed into two cascaded 1D transfer functions

$$\boldsymbol{H}(z_h, z_v) = \boldsymbol{H_h}(z_h)\boldsymbol{H_v}(z_v) \tag{2}$$

where $\boldsymbol{H_h}(z_h)$ and $\boldsymbol{H_v}(z_v)$ are horizontal and vertical vectors, respectively.

Next, 1D lossless matrices have been designed for both $\boldsymbol{H_h}(z_h)$ and $\boldsymbol{H_v}(z_v)$ and cascaded to determine Rosser's matrix

$$\boldsymbol{R} = \begin{bmatrix} \boldsymbol{A} & \boldsymbol{B} \\ \boldsymbol{C} & \boldsymbol{D} \end{bmatrix} \tag{3}$$

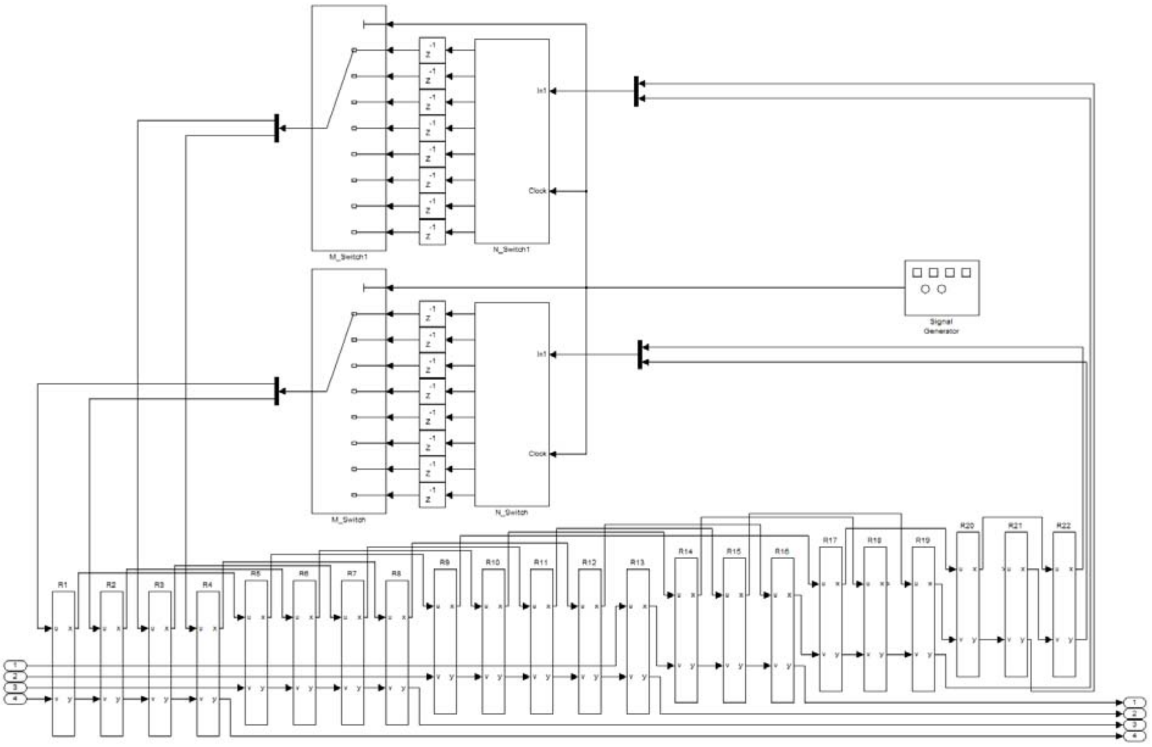

Fig. 4. The rotators structure implementing 2D transfer function (1).

where $\boldsymbol{A}$, $\boldsymbol{B}$, $\boldsymbol{C}$ and $\boldsymbol{D}$ denote matrices described in the Roesser's state space model of 2D linear system defined by the equations

$$\begin{cases} \begin{bmatrix} x^h(i+1,j) \\ x^v(i,j+1) \end{bmatrix} = \boldsymbol{A} \begin{bmatrix} x^h(i,j) \\ x^v(i,j) \end{bmatrix} + \boldsymbol{B}u(i,j) \\ y(i,j) = \boldsymbol{C} \begin{bmatrix} x^h(i,j) \\ x^v(i,j) \end{bmatrix} + \boldsymbol{D}u(i,j) \end{cases} \tag{4}$$

where i and j are integer-valued vertical and horizontal coordinates, respectively,
$x^h(i,j) \in R^h$ and $x^v(i,j) \in R^v$ are the horizontal and the vertical state vectors, respectively,
$u(i,j) \in R^m$ and $y(i,j) \in R^l$ are the input and the output vector, respectively,
$\boldsymbol{A}$, $\boldsymbol{B}$, $\boldsymbol{C}$, $\boldsymbol{D}$ are real constant matrices of $r \times r$, $r \times l$, $k \times r$ and $k \times l$ dimensions, respectively.

Finally, the Roesser's matrix has been rearranged to the following form

$$\boldsymbol{R} = \prod_{i=1}^{n} R_i\,(k_i, l_i, \phi_i) \tag{5}$$

where: n is number of rotators, R_i denote i^{th} rotator between nodes k_i and l_i, with rotation angle ϕ_i.

Applying procedure described by equations (1-5) the structure composed of rotators is determined and illustrated in Table 1 and Figure 4.

TABLE I
UNITS FOR MAGNETIC PROPERTIES

i	k_i	l_i	ϕ_i
1	1	8	-1.5707963
2	1	7	1.4079955
3	1	6	-0.5090086
4	1	5	-0.9543012
5	2	8	1.5707963
6	2	7	-0.4554318
7	2	6	-1.0706747
8	2	5	0.4786330
9	3	8	1.5707963
10	3	7	0.4381944
11	3	6	0.9692243
12	3	5	0.3019199
13	3	4	0.3922403
14	4	7	1.5707963
15	4	6	1.5231193
16	4	5	-0.4182034
17	5	8	-1.6940383
18	5	7	-0.3371344
19	5	6	0.5131796
20	6	8	-0.2113415
21	6	7	-1.4784787
22	7	8	1.1240437

Obtained structure composed of rotators has been implemented in CPLD circuit and the results of preliminary filtering are shown in Figure 6. The structure shown in Figure 4 has been obtained by simple procedure and does not require very tedious derivations. The procedure does not ensure an optimal solution composed of minimal number of rotators, but the complexity of the solution is sufficient for our implementation possibility. The optimal solution may be obtained by the methods presented in [5, 6]. To obtain lossless optimal rotators structure, a solution of a set of nonlinear equations is required.

The example of guiding process recorded by CCD camera from optical testing system with auto-guiding system is shown in the pictures. The reference CCD frame is taken and next improved by unnoise and sharp filtering. After this it is analyzed and its small part is chosen for next calculating. The source reference frame is shown in Figure 5.

The six bright stars have been chosen for guiding. The same stars are marked by small square in Figure 1, the bright stars up right side of M109 galaxy. Movement of the guide stars can be detected in a next frames from the CCD camera. Next frame is taken after a few seconds. If the guide stars are at different position then the mount drives incorrectly and needs correction. The shift of guide stars is calculated from convolution of reference picture and next frame. In Figure 6 is shown the picture whit shifted stars after digital filtering. In order to sharpen star outline and noise filtration the proposed 2D high-pass filter was applied. Next the picture is rotated for proper convolution process in future.

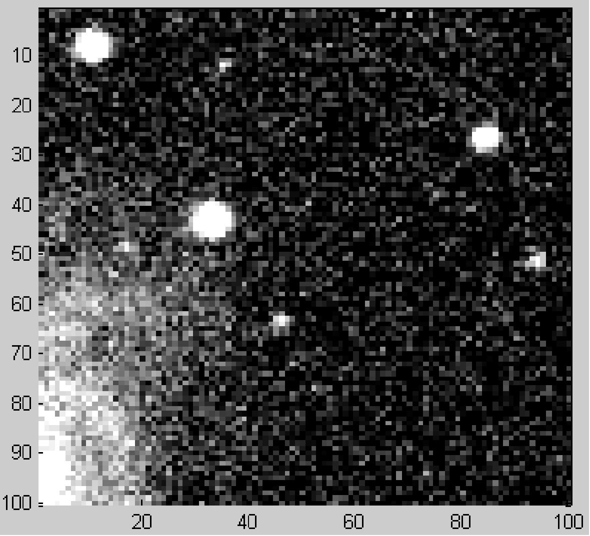

Fig. 5. The reference region of the picture with six bright stars.

If the mount drives incorrectly then guide stars' shift is calculated. Mathematical formula is two-dimensional convolution of next frame and reference picture. The highest value of convolution matrix determines guide stars movements. The coordinates of bright point in Figure 7 mark are corresponding to a new position of six bright stars from reference picture. According this position the system generated drive correction signal for ST4 compatible guide star tracking system.

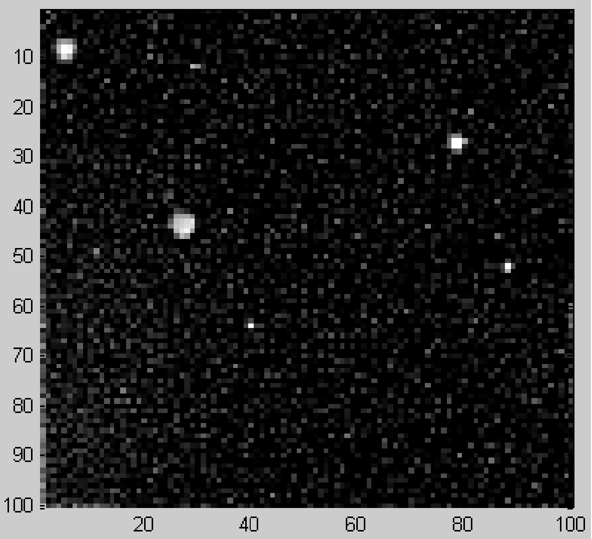

Fig. 6. The reference region of the next frame with six bright stars after unnoise and sharp filtering.

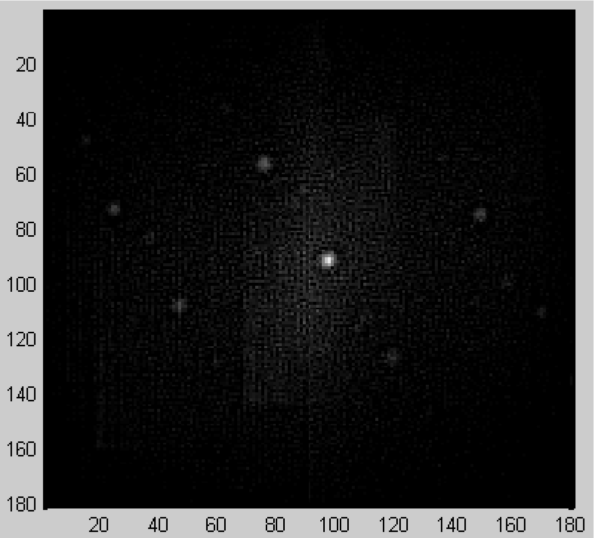

Fig. 7. Result from the convolution of two CCD frames picture; position of the bright point is corresponding to the objects movement.

The convolution process accuracy is presented in Figure 8. The spike in the picture represented the highest value of the convolution matrix corresponding with guide stars movement. A distance between this value and rest of signals is so high that we can determine this movement with high reliability.

Images processing is made by digital circuits. They consist of: FIFO memories, rotators, shift registers and arithmetic circuits. In this project the models of auto-guiding system functional blocks were designed at Simulink - a part of Matlab program. It makes possible to simulate system operation with real data from CCD camera.

These models enables selection of suitable filtration algorithms, memories and arithmetical blocks optimization and the first auto-guiding system functionality test. The Matlab model was tested for real data of astronomical object images. Data from CCD frames have been serial loaded and calculated with proposed methods. The results were stored as new frames.

In the next step, all functional blocks modeled in Matlab were implemented at CPLD circuit. Altera MAX II CPLD devices with development board and Quartus II software was used in this project. The same data from CCD camera were prepared and loaded to implemented auto-guiding test system, and then processed. The similar results of data processing were obtained. It confirms property of proposed solution.

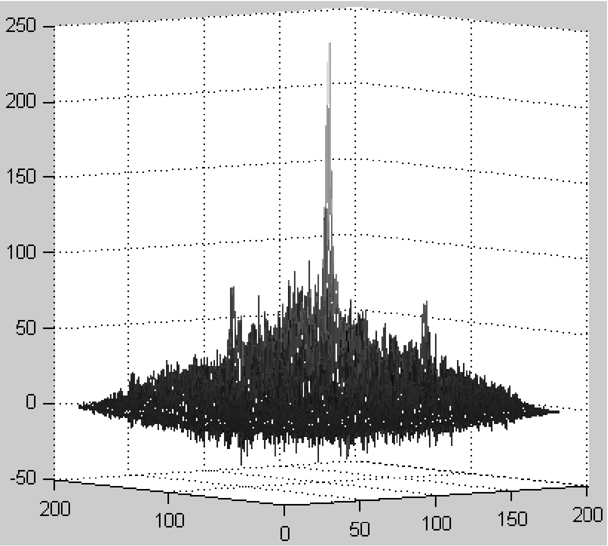

Fig. 8. Result from convolution of the two CCD frames; the point of the maximal value is the movement co-ordinates.

IV. CONCLUSION

In this paper circumstances and main guidelines for building dedicated auto-guiding system, which can be useful for long exposure Deep Sky Object astrophotography, were presented. The Matlab model was designed for optimization and functionality testing of digital circuit. Next the implementation at Altera MAX II CPLD devices was performed. The example of digital signal processing block is shown. The same calculation for real data of astronomical object from CCD camera at Matlab model and CPLD testing board were carried out. Both methods gave the same results. Images acquisition and digital processing speed of test board were sufficient for correct equatorial mount guiding. The CPLD prototype can be used for auto-guiding system in long time astrophotography.

REFERENCES

[1] H. Lee, G. E. Sobelman, “Performance evaluation and optimal design for FPGA-based digit-serial DSP functions”, Computers and Electrical Engineering, vol. 29, no. 2, pp. 357-377, March 2003.

[2] K. Bondalapati, V. K. Prasanna, “Reconfigurable computing systems”, Proceedings of the IEEE, vol. 90, no. 7, pp. 1201- 1217, July 2002.

[3] Suszyński R., „Convolution Method for CCD Images Processing for DSO Astrophotography”, in proc. in proc. 52nd International Midwest Symposium on Circuits and Systems (MWSCAS’09), Cancun, Mexico, 2009.

[4] L.P. Wang, S.H. Hu, X.Y. Zhang, “Detecting and Tracking of Small Target Under the Background of Sea Level” Proceedings of the 9th International Conference on Signal Processing, vol. 2, pp. 989-992, Beijing, China, 2008.

[5] R. Wirski, K. Wawryn, „Roesser’s Model Realization of 2-D FIR Lossless Transfer Matrices”, Proceedings of the International Symposium on Information Theory and its Applications, ISITA’08, Auckland, New Zealand, 2008.

[6] K. Wawryn, R. Wirski, „Synthesis of 2-D Lossless FIR Transfer Function Matrix”, Proceedings of the 7th International Conference on Information Communications and Signal Processing, (ICICS’09), Macau, China, 2009.