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DEVISING A FAST MEDIAN FILTERING PROCEDURE FOR ALIGNING THE NOISE BACKGROUND OF A DIGITAL FRAME

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The object of this study is the process of filtering astronomical frames that contain images of objects in the Solar System. In order to recognize the image of an object in contrast with the background of the frame, it is necessary to filter the image. It is proposed to use a modification of median filtering to reduce the dynamic range of the background substrate. This will lead to an increase in the signal-to-noise ratio of the entire image. However, the identified problem area of each image during filtering is the distortion of the image structure and artifacts. Therefore, to solve this problem, a fast median filtering procedure has been proposed to eliminate them.

A new technique for sorting the brightness of pixels in the median filter window using a histogram has been proposed. For comparison, a classic median filter was chosen with a modification, namely, with the use of quick sorting. The disadvantage of this modification is the fact that during sorting, all the pixels that fall into the median filter window are used every time while sorting using a histogram makes it possible to add and remove from the histogram only those pixel values that appear when the window is shifted.

The devised procedure of fast median filtering was tested in practice within the framework of the CoLiTec project. It was implemented at the stage of in-frame processing of the Lemur software.

This study showed that the application of the fast median filtering procedure makes it possible to remove structural distortions and image artifacts, which leads to an increase in the signal/noise ratio by 3–5 times. Also, owing to sorting with the help of a histogram, the number of comparisons in the median filter window was reduced by 4–30 times, depending on the size of the window. As a result, this led to a decrease in the calculated time by 3–9 times

Keywords: fast median filtering, brightness histogram, sorting, structure distortion, astronomical image

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1. Introduction

Observational astronomy [1] has been developing based on the constant improvement of various methods of astrometry [2] and photometry [3]. Due to the commissioning of large telescopes and the development of digital technologies, the generated astronomical data (usually digital frames or videos) are gradually becoming big data [4]. This is made possible by telescopes equipped with very large charge-coupled device (CCD) cameras [5]. During any type of processing (intra-frame or inter-frame) of digital frames individually or a series of digital frames as a whole, very cumbersome astrometric and photometric catalogues with reference stars [6] are still used. This makes it possible to accumulate, obtain knowledge [7], and analyze accumulated publicly available data [8] and measurements for each solar system object (SSO) (e.g., asteroids or comets), as well as artificial Earth satellites (AESs). Typically, such objects are categorized by specific features/patterns [9] belonging to different classes of SSOs [10] or AESs.

To recognize the image of each such object in contrast with the background of the frame, it is necessary to filter the image. It is used to process digital signals and images in order to reduce noise, especially pulse noise (for example, "salt and pepper"), while maintaining sharp object boundaries. Filtering is a preparatory stage of intra-frame processing of a digital frame, which allows for the alignment of the noise background [11].

Practical use of the proposed fast median filtering procedure could improve the signal-to-noise ratio (SNR) of both the entire image and its fragments, depending on the parameters of the filters used. Continuous improvement of digital frame filtering methods is relevant and involves striving to increase the accuracy of estimating the brightness and positional coordinates of objects at the stage of intra-frame processing of a digital frame [12].

2. Literature review and problem statement

Despite the fact that the resolution of digital frames is increasing owing to modern CCD matrices, the key problem is still the poor quality of the images of the objects themselves in the frame. The consequence of this is the non-uniformity of the typical shape of images of such objects [13], both single and all in the frame (with synchronous blur). The main factors deteriorating the quality of digital frames are failure of daily tracking and various aberrations of the optical system, for example, vignetting, telescope coma, parasitic illumination, etc. [14]. This leads to the appearance of hot/cold pixels, structural distortions, and image artifacts.

In [15], the use of a classical method of pattern recognition is proposed. Such patterns involve analysis and verification of all pixels for matches to determine the typical shape of object images. However, the issue of the presence of non-uniformity of the typical shape remains unresolved. Because of this, confusion arises between objects. Another disadvantage is the inability to accurately outline images of objects with a non-standard pattern.

In [16], the authors propose a matched filtering algorithm for working with blurred images. This is rational for processing images with a variety of typical shapes. However, this solution is based solely on the use of an analytical model to form a typical shape. Therefore, its main disadvantage is its limited application: such a model is only suitable for objects whose typical shapes can be described by standard mathematical expressions. If the object has a non-standard shape, the analytical model becomes ineffective, which significantly reduces the accuracy of the algorithm.

There are classical linear filters for signal and image processing that transform data using a linear mathematical operation [17]. Linearity means that the filtering result is proportional to the input data. The most well-known are the Gaussian filter, the Sobel filter [18], the Laplace filter, and the Fourier filter [19]. They are widely used for smoothing, noise removal, edge detection, and other tasks. However, all linear filters have major drawbacks: they blur the edges and small details of object images, are ineffective in eliminating impulse noise (artifacts), and their linear nature limits their ability to adapt to complex data structures (typical form).

Work [20] proposes using a nonlinear median filter and its modifications (adaptive median filter and weighted median filter). This filter and its modifications make it possible to smooth out the noise background but also have their drawbacks. Namely, high computational complexity, long computation time, smoothing of small details (textures can be lost if their size is smaller than the filter window), and sensitivity to the window size.

Image processing methods based on deep machine learning [21, 22] can only be used for standardized typical shape of object images, as well as using large preset datasets. In the case of a non-standard typical shape, such methods are unable to select the appropriate recognition pattern, which leads to either the loss of the object or its false detection (triggering an artifact or noise).

Studies [23, 24] propose the use of neural networks for digital image processing. However, when processing astronomical images with artifacts and illumination, this approach also has its drawbacks. Namely, the lack of training data (datasets), the inability to work with new types of data without additional training, problems with retraining, and a high computational load. And the main drawback affecting the detection accuracy indicators is sensitivity to noise and artifacts. Artifacts such as cosmic rays, hot pixels, or satellite traces can be mistakenly interpreted by the network as astronomical objects. This is especially critical for classification or detection tasks.

Thus, the problem of our study relates to the fact that existing image preprocessing methods are not adapted to structural distortions caused by aberrations of optical systems. Another drawback is the inability to have a single algorithm for leveling the brightness background of the substrate in the case of parasitic illumination or artifacts.

3. The aim and objectives of the study

The aim of our study is to align the noise background of a digital frame during image preprocessing. From a practical point of view, this will make it possible to increase the degree of uniformity of the background component and, accordingly, the SNR.

To achieve this goal, the following tasks were set:

– to sort pixel brightness using a histogram;

– to calculate the median in the initial position of the median filter window;

– to develop an algorithm for the fast median filtering procedure;

– to verify the fast median filtering procedure.

4. The study materials and methods

The object of our study is the process of filtering astronomical frames that may contain images of potential SSOs. The work accepts the working hypothesis that the procedure of fast median filtering will make it possible to align the noise background of a digital frame during the preliminary processing of images. It was suggested that this could significantly reduce the computational complexity and calculation time, and would also lead to an increase in the SNR across the entire frame. Within the framework of the study, a simplification was adopted that there is no synchronous blur on the frame, and the typical shape of the images of all objects is uniform.

As a filtering method used for comparison, a classic median filter was chosen, but with a modification in the form of using quick sorting [25]. This modification prevails over the classic median filter, as well as its other modifications, due to the fastest calculation time.

As a theoretical research method, a statistical method was chosen [26]. This method was chosen for preliminary testing of the proposed hypothesis before natural experiments.

During the experimental studies, natural initial test series obtained from different telescopes installed at various observatories in Ukraine and around the world were used. Namely, the ISON-NM observatory; the SANTEL-400AN telescope (New Mexico, USA); National Astronomical Research Institute of Thailand (NARIT, Thailand); Vihorlat

Observatory; the VNT telescope (Humenne, Slovakia); Odesa-Mayaky observatory, the OMT-800 telescope (Mayaki, Ukraine) [27]; Takahashi BRC-250M (Uzhhorod, Ukraine).

The conditions of observations and daily operation of the telescopes to obtain natural data were carefully selected. That made it possible to specifically obtain series of frames that contain different typical forms of object images, as well as structural distortions and artifacts. Astronomical frames were considered for working with the following resolution values: 512×512, 768×512, 3056×3056, and 4008×2672 pixels.

The proposed fast median filtering procedure was implemented in the C++ programming language. The resulting procedure code was used at the pre-processing stage in the Lemur software (Ukraine) [28]. It is designed for automatic search, detection of new and support of already known SSOs within the framework of the CoLiTec project [29]. The procedure implemented in the Lemur software (Ukraine) was used for successful processing of astronomical frames, in which a total of more than 800,000 SSOs were detected. The measurement data were identified with known astro- and photometric catalogs without errors and object confusion. This fact has confirmed the practical necessity of the fast median filtering procedure within the framework of the working hypothesis that was tested.

5. Results of the fast median filtering procedure study

5. 1. Sorting pixel brightness using a histogram

The brightness of each pixel of a digital frame is limited by a certain set of known values. For example, for 8-bit images, the set of possible pixel brightnesses is 256, for 16-bit images – 65536. Therefore, to sort brightness, it is proposed to use a histogram represented as a set with elements h[i].

This paper proposes considering a histogram as a variant of representing a set of integers. In this set, the number of the histogram element corresponds to the value of the integer, and the value of this element – to the number of elements of this set equal to this number.

Thus, the number of each histogram element i corresponds to the expected brightness values of each corresponding pixel of the frame. Then the histogram i can change in the following limit $0, N_h-1$. The size of the histogram N_h during programming the procedure in the C++ language was taken to be $N_h=2^{16}=65536$. This means that this histogram size is calculated for using 16-bit images for verification. Thus, this size of the array allocated for the histogram size makes it possible to store both 8-bit images and 16-bit images.

Based on the above, the proposed histogram of the image pixel brightness in the median filter window is shown in Fig. 1.

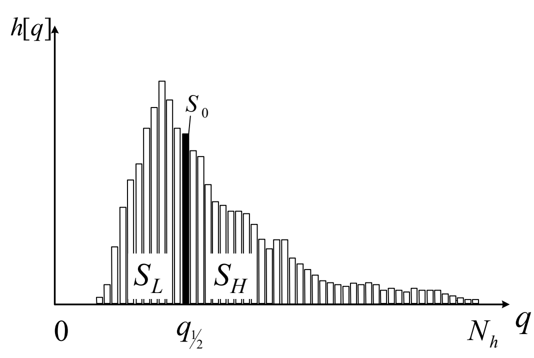

Fig. 1. Histogram of image pixel brightness in the median filter window

This paper proposes characterizing the pixel brightness histogram by four values. Namely, the number of pixels in the median filter window:

$$S_W=d^2, \tag{1}$$

where d is the size of the square window of the median filter.

The set of pixels in the window of the median filter whose brightness values are equal to the median $A_{1/2}$:

$$S_0=h[A_{1/2}]. \tag{2}$$

The set of pixels in the median filter window whose brightness values are less than the median $A_{1/2}$:

$$S_L=\sum_{i=0}^{A_{1/2}-1} h[i]. \tag{3}$$

The set of pixels in the median filter window whose brightness values are greater than the median $A_{1/2}$:

$$S_H=\sum_{i=A_{1/2}+1}^{N_h-1} h[i]. \tag{4}$$

Taking into account the above, the following relationships can be introduced, which will hold:

$$S_L+S_0+S_H=S_W; \tag{5}$$

$$S_L \le E\left[S_W/2\right]; \tag{6}$$

$$S_H \le E\left[S_W/2\right], \tag{7}$$

where $E[\cdot]$ is an operation that determines the integer part of a number.

Our work also assumes that the equal sign in expressions (6) and (7) is possible only when $S_0=1$.

After sorting the pixel brightness using the histogram, it is necessary to calculate the median in the initial position of the median filter window.

5. 2. Calculating the median in the initial position of the median filter window

The array consisting of the histogram elements is preliminarily equal to zero. For each pixel with brightness i in the initial position of the median filter window, the corresponding histogram element with number i is incremented by 1. Then, for the filter window centered at the pixel with numbers $m_{med}=(d-1)/2$ and $n_{med}=(d-1)/2$, the following relation holds:

$$h[A_{in\,add}(m,n)]=h[A_{in\,add}(m,n)]+1, \tag{8}$$

where:

$$m=\overline{m_{med}-(d-1)/2, m_0+(d-1)/2},$$

$$n=\overline{n_{med}-(d-1)/2, n_0+(d-1)/2}.$$

The median of a set of integers is equal to the median of the given set, represented in ordered form. In this case, the median $A_{1/2}$ of an ordered set of integers is equal to the number of the histogram element that contains the element with the number $E[d^2/2]+1$ (the middle element) of the ordered set Ω_A:

$$A_{1/2} = \sum_{k=0}^{A_{1/2}} h[k] > E[d^2/2]+1, \ at \ \sum_{k=0}^{A_{1/2}-1} h[k] \le E[d^2/2]+1. \quad (9)$$

Based on the obtained median $A_{1/2}$, the values of S_0, S_L and S_H are calculated according to (2) to (4):

$$S_0 = h[A_{1/2}]; \quad (10)$$

$$S_L = \sum_{i=0}^{A_{1/2}-1} h[i]; \quad (11)$$

$$S_H = \sum_{i=A_{1/2}+1}^{N_h-1} h[i]. \quad (12)$$

The obtained median $A_{1/2}$ value is assigned to the pixel value of the filtered image $A_{med}(m, n)$ with numbers $m=m_{med}-(d-1)/2$ and $n=n_{med}-(d-1)/2$.

After calculating the median in the initial position of the image median filter window, one can proceed to direct filtering of the entire image using the proposed fast median filtering procedure.

5. 3. Development of the fast median filtering procedure algorithm

The preliminary stage of the fast median filtering procedure was the calculation of the median in the initial position of the image median filter window. This paper proposes not to re-build the histogram after shifting the median filter window by one pixel along the abscissa. Then the histogram can be adjusted using the data from the previous median filter window together with the values of S_0, S_L and S_H.

In the proposed algorithm, the excluded (left) column is the previous column or the column of the initial median filter window (in Fig. 2, the pixels of such a column are marked with the "-" sign). The added (right) column is the column of the current median filter window (in Fig. 2, the pixels of such a column are marked with the "+" sign).

Thus, the fast median filtering procedure algorithm includes the following sequence of actions:

1. For each considered pair of pixels of the excluded column with brightness value $A^-_{in\,add}$ and the added column with brightness value $A^+_{in\,add}$, the following operations are performed.

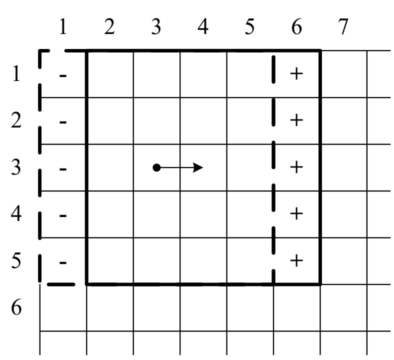

Fig. 2. Shift the median filter window to the right along the abscissa axis across the frame

2. The pixels of each pair are removed from the histogram and added to it:

$$h[A^-_{in\,add}] = h[A^-_{in\,add}] - 1; \quad (13)$$

$$h[A^+_{in\,add}] = h[A^+_{in\,add}] + 1. \quad (14)$$

3. Next, the values of the S_L, S_H and S_0 parameters are specified for the pixels of the left column:

$$\begin{cases} S_L = S_L - 1, at\ A^-_{in\,add} < A_{1/2} \\ S_H = S_H - 1, at\ A^-_{in\,add} > A_{1/2} \\ S_0 = S_0 - 1, at\ A^-_{in\,add} = A_{1/2} \end{cases}. \quad (15)$$

and the right column:

$$\begin{cases} S_L = S_L + 1, at\ A^+_{in\,add} < A_{1/2} \\ S_H = S_H + 1, at\ A^+_{in\,add} > A_{1/2} \\ S_0 = S_0 + 1, at\ A^+_{in\,add} = A_{1/2} \end{cases}. \quad (16)$$

4. After changing the values of S_L, S_H and S_0 according to (15), (16), the value of the median $A_{1/2}$ of the histogram with removed and added pixels $A^-_{in\,add}$ and $A^+_{in\,add}$ is determined. To find the current value of the median $A_{1/2}$, it is necessary to specify the values of S_L, S_H and S_0 so that they satisfy relations (5) to (7).

5. In the case when the set of pixels S_L, whose brightness is less than the median, exceeds half of all the pixels of the window (i.e., condition (6) is not satisfied), then the histogram element, whose number is equal to the median $A_{1/2}$, is added to the set of pixels S_H, whose brightness values are greater than the median:

$$S_H = S_H + h[A_{1/2}]. \quad (17)$$

6. After this, the value of the median itself $A_{1/2}$ is decremented by 1:

$$A_{1/2} = A_{1/2} - 1. \quad (18)$$

7. The histogram element with a brightness less than the median $A_{1/2}$ and a number equal to the new median $A_{1/2}$ value is subtracted from the total number of pixels S_L:

$$S_L = S_L - h[A_{1/2}]. \quad (19)$$

8. Next, a new value of the set of pixels S_0 with brightnesses that are equal to the median $A_{1/2}$ is calculated:

$$S_0 = S_W - S_L - S_H. \quad (20)$$

9. The values of S_L, S_H, S_0 and $A_{1/2}$ are specified according to expressions (17) to (20) until the S_L value satisfies relation (6).

10. In the case where the set of pixels S_H, whose brightness is greater than the median, exceeds half of all the pixels in the window (condition (7) is not satisfied), then the histogram element whose number is equal to the median $A_{1/2}$ is added to the set of pixels S_L, whose brightness values are less than the median:

$$S_L = S_L + h[A_{1/2}]. \quad (21)$$

11. After this, the value of the $A_{1/2}$ median itself is incremented by 1:

$$A_{1/2} = A_{1/2} + 1. \tag{22}$$

12. The histogram element with the number equal to the new $A_{1/2}$ median value is subtracted from the number of pixels S_H whose brightness is greater than the median:

$$S_H = S_H - h[A_{1/2}]. \tag{23}$$

13. After this, a new value of the set of pixels S_0 with brightnesses that are equal to the median $A_{1/2}$ is calculated:

$$S_0 = S_W - S_L - S_H. \tag{24}$$

14. Next, the values of S_L, S_H, S_0 and $A_{1/2}$ are refined according to expressions (21) to (24) until the S_H value satisfies relation (7).

After performing one iteration of the procedure for all pixels from the left and right columns (Fig. 2), the resulting $A_{1/2}$ median value corresponds to the average brightness of the pixels in the current median filter window.

The iteration cycle continues until the lower right edge of the original image is reached.

5. 4. Verification of the fast median filtering procedure

To verify the proposed fast median filtering procedure, testing was carried out on a series of frames obtained from different telescopes.

The following criteria were used as evaluation criteria in our work: complexity of calculations, number of comparisons in the median filter window, calculation time, and SNR. The following values of the sizes of the square window of the median filter were used: 3×3, 5×5, 7×7, 9×9, 11×11, 13×13.

Examples of the results of preliminary processing of the original images (Fig. 3, *a*, *c*) using the devised fast median filtering procedure are shown below (Fig. 3, *b*, *d*).

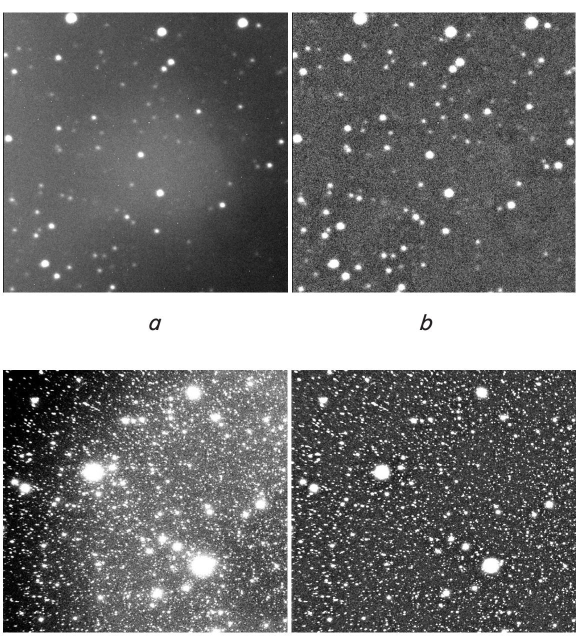

Fig. 3. Examples of astronomical frames with artifacts and flares: *a*, *c* — original image; *b*, *d* — after processing with the fast median filtering procedure

Research has shown that the computational complexity of the median filtering method with quick sorting is $O(n^2)$. Note that the computational complexity of the proposed fast median filtering procedure using a histogram is $O(n)$.

Below, Table 1 gives the resulting indicators of the number of comparisons in the median filter window with different values of the sizes of its square window. The data are represented as average values based on the measurements obtained from 1000 experimental runs.

Table 1

Indicators of the number of comparisons in the median filter window

The size of the median filter window	Quick sorting, w/d	Sorting by histogram, w/d
3×3	47.13	11.63
5×5	128.41	14.71
7×7	251.24	18.21
9×9	418.67	21.88
11×11	631.73	25.64
13×13	877.59	29.43

Table 2 gives the resulting computation time values with different values of the median filter square window sizes. The data are represented as average values based on the obtained measurements from 1000 experimental runs.

Table 2

Computing time indicators

The size of the median filter window	Quick sorting, s	Sorting by histogram, s
3×3	137.5	45.3
5×5	216.3	52.7
7×7	341.7	65.3
9×9	495.2	75.1
11×11	673.8	86.8
13×13	948.3	97.9

Fig. 4 depicts the curves (1 – for median filtering with quick sorting, 2 – for the proposed procedure of quick median filtering using a histogram), constructed based on Table 1. The abscissa axis shows the values of pixels that completely cover the square window of the median filter in pixels. The ordinate axis shows the average values of the number of comparisons in the median filter window.

Fig. 5 shows the curves (1 for median filtering with quick sorting, 2 for the proposed procedure of quick median filtering using a histogram), constructed based on Table 2. The abscissa axis depicts the values of pixels that completely cover the square window of the median filter in pixels. The ordinate axis shows the average values of the computation time.

Fig. 6 shows the dependence plot of SNR before filtering on SNR after applying the proposed fast median filtering procedure.

The results of our study illustrated in Fig. 3–6 and given in Tables 1, 2 indicate successful verification of the proposed procedure and confirmation of the proposed hypothesis.

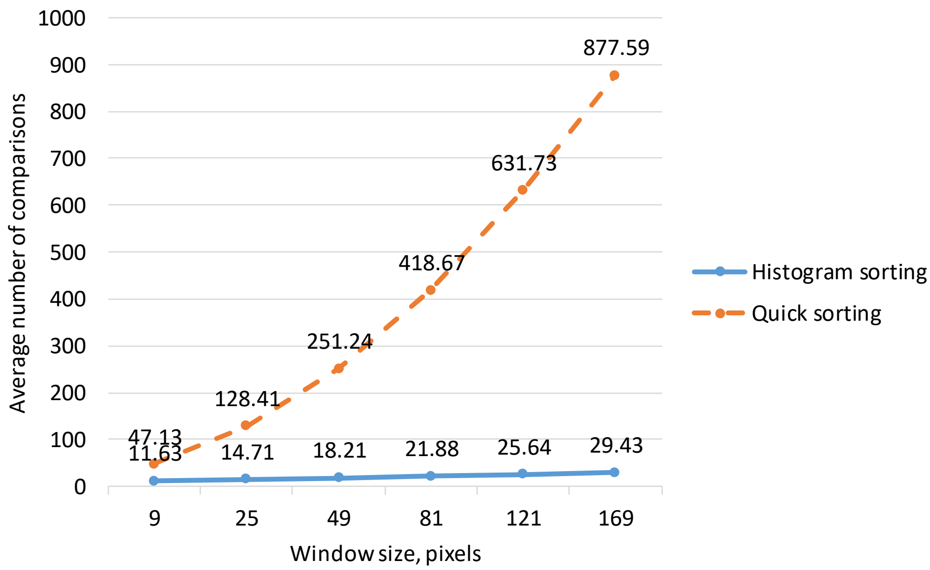

Fig. 4. Curves of average values of the number of comparisons in the median filter window

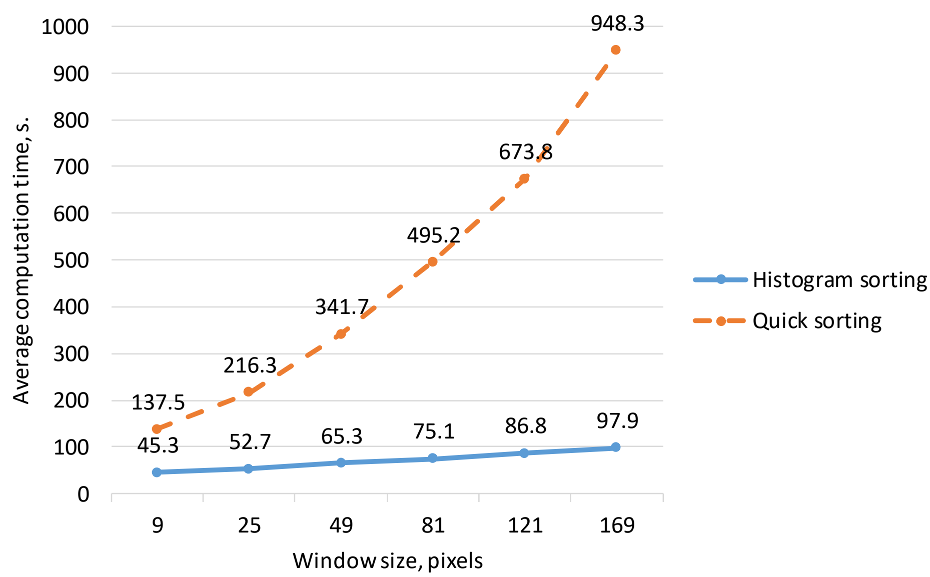

Fig. 5. Curves of averaged computation time values

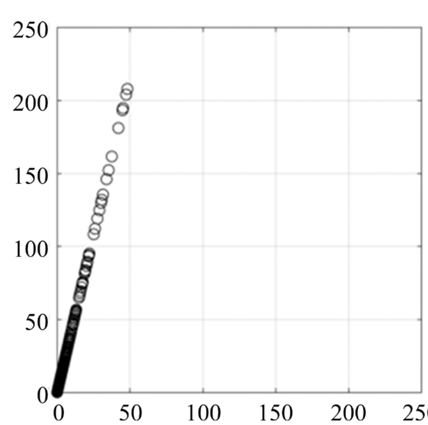

Fig. 6. Dependence plot of the signal-to-noise ratio before filtering on the signal-to-noise ratio after filtering

6. Discussion of results based on investigating the fast median filtering procedure

Within the framework of the CoLiTec project [30] and the Lemur software (Ukraine), a study of the fast median filtering procedure for leveling the noise background of astronomical frames was conducted.

It was proposed to use a histogram (Fig. 1) to sort the pixel brightness in the median filter window. For this purpose, the pixel brightness histogram was characterized by four values. Namely, the total number of pixels in the median filter window, as well as the number of pixels in the median filter window with brightness values equal to, less than, and greater than the median (1) to (4).

That has made it possible to calculate the median in the initial position of the median filter window (9). Then, using expressions (10) to (12), the values characterizing the pixel brightness histogram in the median filter window were refined.

By introducing subtraction and addition of pixel columns in the median filter window into the histogram for sorting, the number of comparisons has significantly decreased, by 4–30 times (Table 1, Fig. 4), depending on the selected window size in pixels. In the classic version of the median filter, all pixels in the window after the shift are used for sorting. However, when modified using fast sorting, this is also significantly longer than in the proposed procedure. Therefore, as a consequence, this also led to a decrease in the calculation time by 3–9 times (Table 2, Fig. 5), depending on the selected window size in pixels.

Analysis of the introduced quality indicator of frame background alignment reveals that as a result of filtering, the frame SNR increases by 3–5 times (Fig. 6). This suggests that the use of the proposed fast median filtering procedure made it possible to remove artifacts and highlights in the image. When compared with studies on the implementation of a number of tasks of object recognition [15, 18] and trajectory detection [9], the result also showed a positive effect on the accuracy of the estimation of the parameters of object images.

Our study and the devised procedure could be successfully applied in programs for processing astronomical images and automatic detection of SSOs, with the estimation of their parameters and obtaining trajectories of movement. It is also possible to apply the results for astrometric and photometric reduction, as well as the formation of light curves and detection curves.

A limitation of our study is the fact that using a fixed filtering window size may not be optimal for processing complex images with different levels of detail and noise.

A disadvantage of the work is that near the edges of the image the median filter has limited information for calculation, which may lead to incorrect processing of these areas.

Further studies will be aimed at using the proposed fast median filtering procedure for subsequent estimation of the brightness of objects (photometry) [19]. Also, from a practical point of view, it will be interesting to apply the proposed procedure not only to the original astronomical frames but also to the calibration service frames [13].

7. Conclusions

1. We have proposed considering the histogram as a variant of representing a set of integers. In this set, the number of the histogram element corresponds to the value of the integer, and the value of this element corresponds to the number of elements of this set equal to this number. Thus, it was possible to sort the pixel values in the median filter window. The histogram was also characterized by four key values, which subsequently made it possible to refine it when shifting the median filter window.

2. The median was calculated in the initial position of the median filter window. That has made it possible to refine the histogram when shifting the median filter window, based on the calculated median.

3. An algorithm for the fast median filtering procedure has been developed. The key point is the introduction of subtraction and addition of pixel columns in the median filter window to the histogram for sorting. That has made it possible to reduce the number of comparisons by 4–30 times.

4. The devised fast median filtering procedure has been verified based on a set of frame series of different sizes and with different median filter window sizes. A significant reduction in the number of pixel brightness comparisons in the median filter window resulted in a 3–9-fold reduction in computation time. Verification of our procedure also showed a significant 3–5-fold reduction in SNR. Visual verification demonstrated compensation for structural distortions, flares, and artifacts after applying the devised procedure.

Conflicts of interest

The authors declare that they have no conflicts of interest in relation to the current study, including financial, personal, authorship, or any other, that could affect the study, as well as the results reported in this paper.

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Data availability

All data are available, either in numerical or graphical form, in the main text of the manuscript.

Use of artificial intelligence

The authors confirm that they did not use artificial intelligence technologies when creating the current work.

References

1. Wheeler, L., Dotson, J., Aftosmis, M., Coates, A., Chomette, G., Mathias, D. (2024). Risk assessment for asteroid impact threat scenarios. Acta Astronautica, 216, 468–487. https://doi.org/10.1016/j.actaastro.2023.12.049
2. Troianskyi, V., Kankiewicz, P., Oszkiewicz, D. (2023). Dynamical evolution of basaltic asteroids outside the Vesta family in the inner main belt. Astronomy & Astrophysics, 672, A97. https://doi.org/10.1051/0004-6361/202245678
3. Troianskyi, V., Godunova, V., Serebryanskiy, A., Aimanova, G., Franco, L., Marchini, A. et al. (2024). Optical observations of the potentially hazardous asteroid (4660) Nereus at opposition 2021. Icarus, 420, 116146. https://doi.org/10.1016/j.icarus.2024.116146
4. Khalil, M., Said, M., Osman, H., Ahmed, B., Ahmed, D., Younis, N. et al. (2019). Big data in astronomy: from evolution to revolution. International Journal of Advanced Astronomy, 7 (1), 11–14. https://doi.org/10.14419/ijaa.v7i1.18029
5. Adam, G. K., Kontaxis, P. A., Doulos, L. T., Madias, E.-N. D., Bouroussis, C. A., Topalis, F. V. (2019). Embedded Microcontroller with a CCD Camera as a Digital Lighting Control System. Electronics, 8 (1), 33. https://doi.org/10.3390/electronics8010033
6. Vavilova, I., Pakuliak, L., Babyk, I., Elyiv, A., Dobrycheva, D., Melnyk, O. (2020). Surveys, Catalogues, Databases, and Archives of Astronomical Data. Knowledge Discovery in Big Data from Astronomy and Earth Observation, 57–102. https://doi.org/10.1016/b978-0-12-819154-5.00015-1
7. Zhang, Y., Zhao, Y., Cui, C. (2002). Data mining and knowledge discovery in database of astronomy. Progress in Astronomy, 20 (4), 312–323.
8. Chalyi, S., Levykin, I., Biziuk, A., Vovk, A., Bogatov, I. (2020). Development of the technology for changing the sequence of access to shared resources of business processes for process management support. Eastern-European Journal of Enterprise Technologies, 2 (3 (104)), 22–29. https://doi.org/10.15587/1729-4061.2020.198527
9. Khlamov, S., Savanevych, V., Tabakova, I., Trunova, T. (2022). The astronomical object recognition and its near-zero motion detection in series of images by in situ modeling. 2022 29th International Conference on Systems, Signals and Image Processing (IWSSIP), 1–4. https://doi.org/10.1109/iwssip55020.2022.9854475
10. Oszkiewicz, D., Troianskyi, V., Galád, A., Hanuš, J., Ďurech, J., Wilawer, E. et al. (2023). Spins and shapes of basaltic asteroids and the missing mantle problem. Icarus, 397, 115520. https://doi.org/10.1016/j.icarus.2023.115520

11. Savanevych, V., Khlamov, S., Briukhovetskyi, O., Trunova, T., Tabakova, I. (2023). Mathematical Methods for an Accurate Navigation of the Robotic Telescopes. Mathematics, 11 (10), 2246. https://doi.org/10.3390/math11102246
12. Bellanger, M. (2024). Digital Signal Processing: Theory and Practice. John Wiley & Sons. https://doi.org/10.1002/9781394182695
13. Vlasenko, V., Khlamov, S., Savanevych, V., Trunova, T., Deineko, Z., Tabakova, I. (2024). Development of a procedure for fragmenting astronomical frames to accelerate high frequency filtering. Eastern-European Journal of Enterprise Technologies, 3 (9 (129)), 70–77. https://doi.org/10.15587/1729-4061.2024.306227
14. Chen, S., Feng, H., Pan, D., Xu, Z., Li, Q., Chen, Y. (2021). Optical Aberrations Correction in Postprocessing Using Imaging Simulation. ACM Transactions on Graphics, 40 (5), 1–15. https://doi.org/10.1145/3474088
15. Al-Sharo, Y. M., Abu-Jassar, A. T., Sotnik, S., Lyashenko, V. (2021). Neural Networks As A Tool For Pattern Recognition of Fasteners. International Journal of Engineering Trends and Technology, 69 (10), 151–160. https://doi.org/10.14445/22315381/ijett-v69i10p219
16. Khlamov, S., Savanevych, V., Vlasenko, V., Briukhovetskyi, O., Trunova, T., Levykin, I. et al. (2023). Development of the matched filtration of a blurred digital image using its typical form. Eastern-European Journal of Enterprise Technologies, 1 (9 (121)), 62–71. https://doi.org/10.15587/1729-4061.2023.273674
17. Burger, W., Burge, M. J. (2022). Digital Image Processing. In Texts in Computer Science. Springer International Publishing. https://doi.org/10.1007/978-3-031-05744-1
18. Khlamov, S., Tabakova, I., Trunova, T. (2022). Recognition of the astronomical images using the Sobel filter. 2022 29th International Conference on Systems, Signals and Image Processing (IWSSIP), 1–4. https://doi.org/10.1109/iwssip55020.2022.9854425
19. Vlasenko, V., Khlamov, S., Savanevych, V. (2024). Devising a procedure for the brightness alignment of astronomical frames background by a high frequency filtration to improve accuracy of the brightness estimation of objects. Eastern-European Journal of Enterprise Technologies, 2 (2 (128)), 31–38. https://doi.org/10.15587/1729-4061.2024.301327
20. Dougherty, E. R. (2020). Digital Image Processing Methods. CRC Press. https://doi.org/10.1201/9781003067054
21. Abdikerimova, G., Yessenova, M., Yerzhanova, A., Manbetova, Z., Murzabekova, G., Kaibassova, D. et al. (2023). Applying textural Law's masks to images using machine learning. International Journal of Electrical and Computer Engineering (IJECE), 13 (5), 5569. https://doi.org/10.11591/ijece.v13i5.pp5569-5575
22. Azhibekova, Z., Bekbayeva, R., Yussupova, G., Kaibassova, D., Ostretsova, I., Muratbekova, S. et al. (2024). Using deep learning to diagnose retinal diseases through medical image analysis. International Journal of Electrical and Computer Engineering (IJECE), 14 (6), 6455. https://doi.org/10.11591/ijece.v14i6.pp6455-6465
23. Halachev, P. (2021). Application of artificial neural networks for prediction of business indicators. Mathematical Modeling, 5 (4), 141–144. Available at: https://stumejournals.com/journals/mm/2021/4/141
24. Turarova, M., Bekbayeva, R., Abdykerimova, L., Aitimov, M., Bayegizova, A., Smailova, U. et al. (2024). Generating images using generative adversarial networks based on text descriptions. International Journal of Electrical and Computer Engineering (IJECE), 14 (2), 2014. https://doi.org/10.11591/ijece.v14i2.pp2014-2023
25. Gonzalez, R., Woods, R. (2018). Digital image processing. Pearson. Available at: https://dl.icdst.org/pdfs/files4/01c56e081202b62bd7d3b4f8545775fb.pdf
26. Shvedun, V. O., Khlamov, S. V. (2016). Statistical modeling for determination of perspective number of advertising legislation violations. Actual Problems of Economics, 184 (10), 389–396.
27. Troianskyi, V., Kashuba, V., Bazyey, O., Okhotko, H., Savanevych, V., Khlamov, S., Briukhovetskyi, A. (2023). First reported observation of asteroids 2017 AB8, 2017 QX33, and 2017 RV12. Contributions of the Astronomical Observatory Skalnaté Pleso, 53 (2). https://doi.org/10.31577/caosp.2023.53.2.5
28. Khlamov, S., Savanevych, V., Briukhovetskyi, O., Trunova, T. (2023). Big Data Analysis in Astronomy by the Lemur Software. 2023 IEEE International Conference on Information and Telecommunication Technologies and Radio Electronics (UkrMiCo), 5–8. https://doi.org/10.1109/ukrmico61577.2023.10380398
29. Khlamov, S., Savanevych, V., Tabakova, I., Kartashov, V., Trunova, T., Kolendovska, M. (2024). Machine Vision for Astronomical Images using The Modern Image Processing Algorithms Implemented in the CoLiTec Software. Measurements and Instrumentation for Machine Vision, 269–310. https://doi.org/10.1201/9781003343783-12
30. Khlamov, S., Savanevych, V., Briukhovetskyi, O., Tabakova, I., Trunova, T. (2022). Astronomical Knowledge Discovery in Databases by the CoLiTec Software. 2022 12th International Conference on Advanced Computer Information Technologies (ACIT), 583–586. https://doi.org/10.1109/acit54803.2022.9913188