Methods and Means of Creating a Software Package for Digital Image Processing*

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Abstract

This paper presents an integrated methodology for designing and implementing a software package aimed at comprehensive digital image processing, combining classical preprocessing techniques with advanced spectral-transform approaches and simulation-based data generation. The developed Digital Image Processing (DIP) package enables the processing of both real images and synthetically generated deterministic or stochastic structures, ensuring controlled experimental conditions for evaluating algorithms. The study addresses key challenges of image enhancement, including noise suppression, contrast adjustment, amplitude and frequency filtering, and contour extraction of high-contrast objects. A set of modelling tools was created for generating polygons, ring-shaped structures, and linear configurations with configurable quantisation parameters and noise models, which significantly expands the capabilities of testing and validation. The proposed algorithms integrate spatial-domain and frequency-domain methods, including median filtering, adaptive amplitude transformations, fast Fourier transform (FFT)-based frequency analysis, functional spectrum transformations, and derivative-based contour detection. Software modules implementing these algorithms form a unified application package that supports interactive selection of processing scenarios and iterative refinement. Experimental results demonstrate increased accuracy, stability, and visual quality of processed images, especially under noisy conditions. The presented approach provides a universal framework for preliminary image enhancement and spectral analysis, with applications in medical imaging, technical diagnostics, industrial monitoring, and automated visual inspection systems. The novelty of the work lies in combining modelling tools with unified preprocessing and spectral-transformation capabilities, ensuring high flexibility and reproducibility of digital image processing workflows.

Keywords

digital image processing, image processing methods and tools, simulation modelling of digital images, amplitude and frequency filtering, contour selection of contrasting areas, spectral transformations, fast Fourier transform

1. Introduction

Digital image processing methods play a decisive role in interdisciplinary research and are widely used in medicine, industry, aerospace technology, etc. Their use improves the informativeness of visual data, reduces the impact of distortions, and creates conditions for automated analysis of images of various nature. The constant growth in data volumes and increasing demands for processing accuracy necessitate further automation of the relevant procedures.

The Digital Image Processing (DIP) application package, which is discussed in this study, implements a set of tools aimed at improving the quality of primary images. This processing belongs

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to the preliminary preparation stage, the result of which is an image identical in type to the original, but with improved characteristics.

Image quality improvement is usually considered in two aspects. First, such processing can be performed to improve the quality of human visual perception of the image. In this case, quality improvement is the final stage of digital image processing. The second possible option is to pre-process the image for subsequent automatic analysis. In this case, the requirements for the quality of the converted image, and therefore the content of the processing, are determined by the stages of image analysis.

In most cases, image quality assessment is based on the subjective visual perception of the human observer, while the use of objective quantitative indicators is much less common. In the context of automated analysis, the effectiveness of pre-processing is usually evaluated only by the final results of solving the main task, which necessitates considering the methods, algorithms, and results of the initial processing stage in close connection with the subsequent stages of analysis. Along with general issues characteristic of a wide range of tasks, there are also a number of specific problems caused by the properties of specific systems and observation conditions. As a result, it is extremely difficult to formulate a generalised problem of preliminary image processing.

It is advisable to distinguish the main types of transformations that provide an improved image from the original. At the pre-processing stage, two basic classes of transformations are usually considered: geometric and amplitude.

The most common geometric transformation operations include cropping, scaling, and rotating the image. Amplitude transformations are aimed at modifying the brightness structure so that the most important details of the image become more distinct, both for visual evaluation and for automated analysis. In this context, amplitude transformations are used to improve the quality of input data.

This class includes methods implemented in the Digital Image Processing application package, among which are contrast adjustment, amplitude filtering, background component removal, line structure enhancement, frequency filtering, and contour enhancement of contrasting areas.

The novelty of the article lies in the creation of a universal software package that combines methods of preliminary and spectral data processing with the use of simulation modeling to generate test data, which increases the accuracy, efficiency, and reliability of digital image processing.

2. Methodology and Results

Digital image processing covers a wide range of tasks related to methods of forming, representing, transforming, transmitting, and storing visual data [9, 10]. The application software package (ASP) presented in this study is focused on solving digital processing tasks and involves working with both real images and those created by simulation modelling [24]. This approach makes it possible to generate deterministic and stochastic structures of the required configuration and then process them digitally.

The development of effective image pre-processing algorithms requires large-scale experiments to determine their characteristics. In this context, the use of simulation modelling, which allows the reproduction of various types of input data, is of particular importance. The modelling of deterministic images of objects and processes is an important stage in research.

The scope of digital image processing is extremely broad and covers the analysis of visual images. Unlike humans, who perceive only electromagnetic radiation in the visible range, information technologies allow us to work with virtually the entire spectrum of waves, from ultrasonic to electron microscopy data [14].

There is no clear universal criterion that would distinguish image processing from related fields, such as image analysis or machine vision systems. It is generally believed that a characteristic feature of processing is the use of images as both input and output signals. Within a wide range of tasks, from elementary operations to machine vision systems, three levels of processes can be conditionally distinguished [20].

Low-level processes include basic operations such as noise reduction or contrast enhancement, where the result is also presented as an image.

Mid-level, which covers segmentation and recognition of individual image fragments, where the output is features, contours, characteristics or new images [7].

High-level processes, focused on interpreting and understanding a set of recognised objects.

In most cases, a digital image is formed through the discretisation and quantisation of a continuous natural signal.

Within the framework of automated image processing, an image can be interpreted as a set of signals whose parameters reflect the intensity of the reflected electromagnetic radiation. During digital processing, a continuous image captured at a specific moment in time is converted through discretisation and quantisation into an array of non-negative readings corresponding to the measured intensity values. During the discretisation process, the plane occupied by the image is divided into a grid of rectangular elements with edges oriented along the coordinate axes. The centres of these elements form a rectangular raster template that defines the spatial arrangement of numerical readings. As a result, a digital image is formed. The array obtained during discretisation is usually represented as a matrix, and image processing operations are interpreted as transformations over matrix structures.

An image is a carrier of information in visual form, and the effectiveness of its perception by humans is determined by a number of factors. The most complete consideration of these factors is possible only if a wide range of issues related to image acquisition methods, visual perception characteristics, and image processing algorithms are studied.

At the present stage, the development of technical and medical diagnostic methods is closely linked to the visualisation of the internal structures of objects [6]. There are many different approaches to visualisation. The emergence of new methods does not replace existing ones, but only expands their range. Each method is based on certain physical principles of interaction between electromagnetic radiation and materials, environments or biological tissues, which makes it possible to measure various physical characteristics of the objects under study.

2.1. Modelling background situations

To implement various transformation algorithms, the primary task is to form a digital image. In cases where there is no real data obtained from imaging systems and corresponding to the object of observation, this task can be solved through modelling [15]. In this case, it is possible to generate images (arrays of readings) of various objects, where the intensity distribution law is set by the researcher.

When creating algorithms for simulating deterministic objects and processes, it is often assumed that images representing the object under study can be represented as combinations of simpler structures. Elementary geometric primitives are used to model them – these are polygons, rings (circles and circles) and linear elements (for example, angles). As a result of forming such structures, a corresponding digital image is obtained. Changing the number of quantisation levels allows you to create models of images of various objects and processes against a zero background.

An important aspect of simulation is taking into account the fact that when images are formed by optical, television or other systems, "deterministic" images are inevitably distorted by noise and interference. They can occur both in recording and transmission devices and in the signal propagation environment. Therefore, taking noise effects into account is a necessary condition for adequate modelling, correct assessment of the quality of digital images, and the development of effective algorithms for their pre-processing and restoration. When simulating background processes (noise), a digital image is formed, where each pixel of the raster matrix is assigned a specific noise value. Such values are obtained as realisations of a random variable that obeys a given distribution law (e.g., normal, uniform, or exponential) with specific parameters that describe the characteristics of the noise signal. This approach makes it possible to model different types of noise characteristic of specific imaging systems and creates conditions for controlled generation of interference for the purpose of testing methods of digital image processing and restoration [13].

In research, noise is usually described as a random variable obtained by using a normally distributed random number generator based on a sequence of uniformly distributed random values.

When modelling images of real objects and processes, a model of background influences is added to the model of a deterministic object or phenomenon. In the additive approach, it is assumed that the recorded signal consists of a useful component and a noise component.

2.2. Pre-processing of images

The effectiveness of image restoration is largely determined by the quality of pre-processing, during which a processed version is formed from the recorded image.

The term "image smoothing" has two main meanings. First, when correcting signal distortions that arise in the imaging system, smoothing involves suppressing noise caused by device imperfections, in particular, additive, fluctuation, impulse, and other types of noise. Secondly, when preparing images, smoothing involves removing small details that complicate the perception of the main objects.

To reduce the effects of noise, a smoothing procedure is usually applied, which, although often performing an aesthetic function, can also be of practical importance for further analysis. Smoothing is considered a two-dimensional analogue of basic signal processing aimed at eliminating noise with frequency components outside the range of the signal transmitted by the channel [8, 25].

There are many methods used to improve observation conditions and facilitate automated image analysis. Some of them work directly in the spatiotemporal domain with the original image representation, while others perform transformations in the frequency domain, operating on the spectral characteristics of the image.

2.3. Pre-processing of images in the spatiotemporal domain

Methods of pre-processing images in the spatiotemporal domain include contrast enhancement, background removal, amplitude filtering, and other similar transformations aimed at improving the visual quality of images and facilitating their further automated analysis [11]. The use of these methods allows the main features of objects to be highlighted, the influence of unwanted noise to be reduced, and data to be prepared for subsequent processing stages in the frequency or other image representation domains [1, 12].

The main goal of enhancement methods is to transform images so that they become more contrasting and informative. Often, local distortions are observed in an image due to light diffraction, optical system defects, or defocusing, which requires local transformations. An adaptive approach allows the most informative areas to be highlighted and processed accordingly.

Low contrast is one of the most common defects in photographic and television images, arising from the limited range of reproducible brightness levels and often combined with the non-linearity of the transmission characteristic. In many cases, contrast enhancement is achieved by correcting the brightness of individual pixels according to a selected characteristic that corresponds to specific tasks. For digital images, obtaining the required level transfer characteristic is relatively simple. When using non-linear operators, possible quantisation errors should be taken into account [5], as an insufficient number of levels can cause artefacts such as false contours.

A background image is characterised by the fact that the intensity of each pixel is a random variable. The task of background filtering is to remove these noise components from the output image readings with minimal distortion of the useful signal. One common approach to this is non-linear processing using median filtering.

Amplitude filtering aims to highlight or suppress image elements whose intensity is within specified limits. This task can be effectively solved using an image contrast modification approach.

2.4. Preliminary processing of images in the frequency domain

Methods of image processing in the frequency domain involve performing two-dimensional transformations, such as Fourier transforms, modifying the resulting spectrum, and calculating the inverse transform to obtain an improved image [2]. Examples of such methods are low-frequency and high-frequency filtering, with high-frequency filtering being particularly effective for highlighting object contours through frequency domain image analysis. The use of spectral transformations in the processing process can significantly improve image quality and subjective perception.

Spatial differentiation methods, in particular through spatial derivatives, can be used to emphasise contour elements. Image restoration based on such spectra allows the contours of the original image to be clearly highlighted in the vertical and horizontal directions [4]. Further combination of the restored images with using amplitude filtering ensures effective highlighting of the contours of contrasting objects.

2.5. Description of the logical structure

At the initial stage of interaction with the user, it is necessary to determine the method of forming the input image – loading from an external source or generating it using software modelling. At the next stage, the user selects one of the pre-processing methods: inverse linear scaling, linear scaling, brightness clipping, one-dimensional median filtering, or transition to image analysis in the frequency domain. If frequency domain processing is selected, the user can choose one of four types of operations: image spectrum calculation, spectrum transformation, high-frequency and low-frequency filtering, and object contour extraction. After completing the planned analysis, the user can continue further image processing, return to the initial stage of the package, or finish working with the software complex.

2.6. Image modelling programs

When modelling images in the form of polygons, the initial parameters are the number of sides, arrays of vertex coordinates, the number of quantisation levels, and the noise index. In the absence of noise, a deterministic object or process is formed, i.e., an image of a real object or process. To model the background situation, noise parameters are additionally specified, in particular for a Gaussian random variable – this is the mathematical expectation and standard deviation. The result of the work is a single- or multi-level image of a polygon. When modelling images in the form of a ring, the initial data are the coordinates of the centre, the radii of the outer and inner circles, the number of quantisation levels, and the noise index. As a result, a digital image of the ring is formed. For linear structures, the initial parameters are the angle of inclination of the bisector to the OX axis, the angle between the beam and the bisector, the coordinates of the vertex of the base angle, the distance between the vertices of adjacent angles, the beam thickness (single or double) and the noise index. The program generates the corresponding beam image at the output. The software implementation of contrast modification and amplitude filtering algorithms allows controlling the arithmetic mean value of pixel intensity and highlighting object boundaries, which improves the visual perception of images [16, 22]. The Digital Image Processing (DIP) application package describes one of the approaches to improving image quality. To implement the contrast change and amplitude filtering algorithms, the initial data is the output image and the type of transformation. Amplitude filtering (brightness cut) sets the intensity value at the cut, the start, width, and type of the cut (values outside the cut are reset to zero or remain unchanged). Linear or inverse linear scaling here, the minimum intensity value in the transformed image, the angle of change in the intensity range (angle < 45° when narrowing, angle > 45° when expanding), as well as the presence of restrictions and their parameters for minimum and maximum intensity values are specified. The result of the program is an image converted according to the specified parameters — a brightness slice with or without background preservation, linear or inverse scaling with or without restrictions. The demonstrated results indicate the high efficiency of the image enhancement methods used. The results of the programme implementing the image contrast enhancement method are shown in Figure 1 and Figure 2, respectively.

Figure 1: Image processing by changing contrast: a) initial image; b) image processed by the proposed method.

Figure 2: Image processing by changing contrast: a) initial image; b) image processed using the proposed method.

The results of the programme implementing the method, which allows effective control of the intensity of image pixels, are shown in Figure 3 and Figure 4.

Figure 3: Image processing by changing image brightness: a) initial image; b) image processed using the proposed method.

Figure 4: Image processing by changing image brightness: a) initial image; b) image processed using the proposed method.

2.7. Median filtering programme

Often, when visual data is generated, the images obtained contain noise due to imperfect equipment, external factors, and other reasons, which leads to a deterioration in the quality of image perception and a reduction in the reliability of conclusions made on their basis. Therefore, an urgent task is to eliminate or reduce the level of noise in images. A significant number of studies have been devoted to noise filtering, and various methods and algorithms have been developed [18].

The term "image smoothing" has a double meaning. The first aspect concerns the correction of signal distortions introduced by the imaging system; in this case, smoothing consists in suppressing interference associated with system imperfections, such as additive, fluctuation, and impulse noise. The second aspect is related to image preparation, where smoothing is aimed at removing small details that interfere with the perception of the main objects. One effective method for removing impulse noise is to use a median filter. For a certain class of images, noise suppression can be achieved using low-frequency spatial filtering, especially if the image contains large homogeneous areas of brightness and the noise level is low [3].

The software transforms the original image to reduce or eliminate the noise component. The initial data for the program includes the input image, the size of the filtering window, and the filtering direction (rows or columns). Filtering is performed by applying a one-dimensional median operation to each row or column of the image matrix. After each step, the programme calculates the average intensity value and estimates the relative noise reduction compared to the previous stage. The user determines whether to continue or stop the filtering process. The results of the module that implements the image filtering method are shown in Figure 5, Figure 6, and Figure 7, respectively.

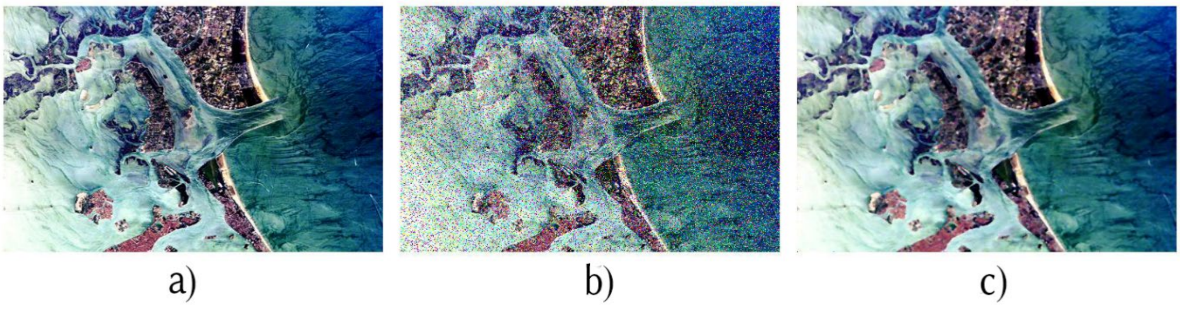

Figure 5: Processing of a noisy image using the median filtering method: a) initial image; b) noisy image; c) image processed by the proposed method.

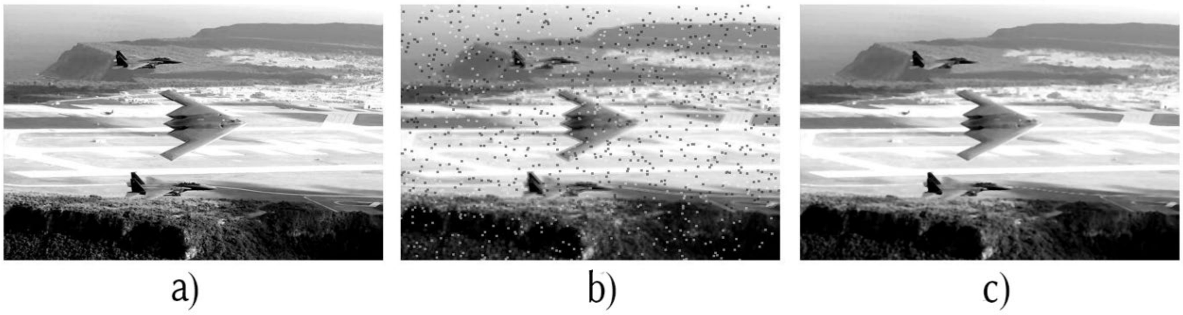

Figure 6: Processing of a noisy image using the median filtering method: a) initial image; b) noisy image; c) image processed using the proposed method.

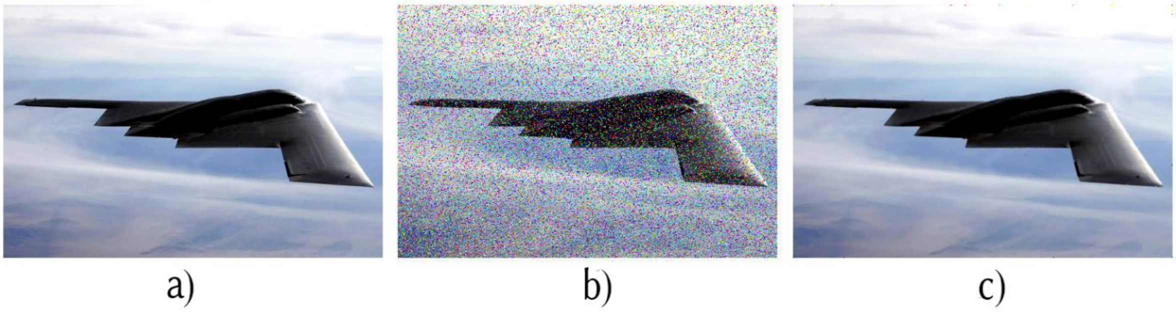

Figure 7: Processing of a noisy image using the median filtering method: a) initial image; b) noisy image; c) image processed using the proposed method.

2.8. Fast Fourier transform program

When implementing the standard algorithm for direct and inverse two-dimensional fast Fourier transform (FFT), the initial image and the following parameters were used as input data: matrix dimension; transform type (direct or inverse FFT). The essence of the transform is to form a transformed image matrix by calculating the sum of the squares of the real and imaginary parts of the spectrum, followed by regrouping the matrix elements. The result of the work is the spectrum of the output image, which is stored in the form of arrays of real and imaginary parts of Fourier coefficients. The software implementation of image frequency processing algorithms converts the array of initial image readings in the frequency domain by selecting or cutting off a specific frequency range [17, 19]. In addition to the image itself, the initial data for the programme includes: filter parameter; filter width; filter type (frequency selection or removal). To perform transformations in the frequency domain, the programme uses forward and inverse FFT.

2.9. Modelling of image processing algorithms with functional spectrum transformation

The software implements image processing algorithms with functional spectrum transformation. After loading the initial image as an array of real numbers representing pixel intensity, the forward FFT mode is activated and arrays of Fourier spectrum coefficients for the output image are calculated. Next, the real parts are entered into the output array, arrays of amplitude and phase components of the spectrum are formed, and then the selected transformation is performed according to the specified parameter.

2.10. Modelling the contour extraction algorithm

Intuitively, the edge of an object in an image is defined as the boundary between two areas with approximately uniform brightness. Edges often appear due to the presence of silhouette lines of objects. One of the main problems in developing edge detection methods is that the assumptions on which they are based are not always valid in real conditions [21, 23]. Another difficulty in creating computational schemes for edge detection is the vague formulation of the task itself: how to determine whether an edge is missing or a false edge has appeared. The answer to this question depends on the purposes for which the result will be used. In the programme that implements the algorithm for extracting contours from contrasting images, after loading the initial image and calculating the Fourier spectrum coefficient arrays, the data is transformed by restoring spatial derivatives in the horizontal and vertical directions, followed by summing the results to form contours. The results of the program that implements the method of object contour extraction in the image are shown in Figure 8, Figure 9, and Figure 10, respectively.

Figure 8: Image processing by selecting object contours in the image: a) initial image; b) image processed by the proposed method.

Figure 9: Image processing by selecting the contours of objects in the image: a) initial image; b) image processed by the proposed method.

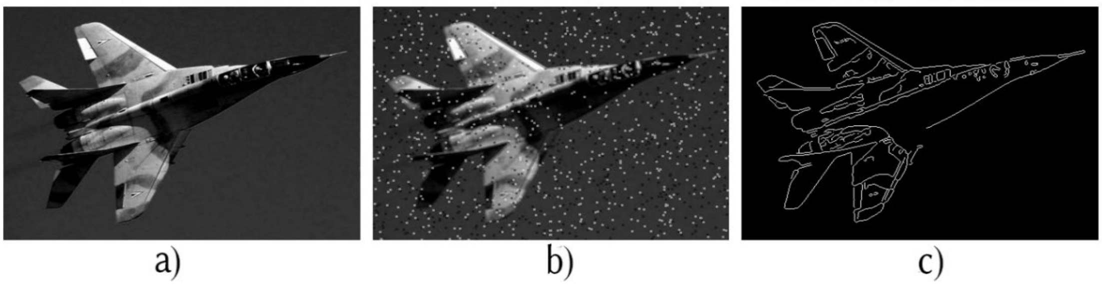

Figure 10: Image processing by selecting object contours: a) initial image; b) noisy image; c) image processed using the proposed method.

3. Conclusion

During the research, algorithms were developed for forming deterministic images of various typical object configurations, in particular polygons, circular figures, and linear structures with different intensity levels. Algorithms for pre-processing images in the space-time domain were created, including methods for contrast enhancement, background removal, and amplitude filtering. Based on the fast Fourier transform algorithm, methods of frequency filtering, contour extraction, and functional spectrum transformation have been developed, which provide an effective solution to the problems of pre-processing images in the frequency domain. For the practical implementation of these algorithms, software modules have been created, which form the basis of the "Digital Image Processing" application package. The significance of the research lies in the fact that modern image processing systems require high accuracy and efficiency in the analysis of visual information. The results prove that the most effective approach to improving image quality is to combine processing methods in the frequency domain with preliminary preparation in the space-time domain. Such research is of great practical importance for the development of modern visualisation, medical diagnostics, industrial control and scientific research, where the accuracy and reliability of processed information is important.

Declaration on Generative AI

The authors have not employed any Generative AI tools.

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