

## Implementation of Smoothing and Noise Reduction for Digital Image Quality Enhancement Using Neighborhood Operations

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### ABSTRACT

The rapid growth in digital imaging technology has brought profound changes to various sectors. However, the quality of digital images is often compromised by noise, such as gaussian noise, salt-and-pepper noise, and spackle noise. Noise not only reduces the aesthetics of an image, but can also hinder image analysis and interpretation. In addition, it can obscure important details in the image and reduce the clarity and accuracy of visual analysis. To improve the quality of digital images, effective smoothing and noise removal techniques are needed, one of which is the neighborhood operation. The main purpose of smoothing and noise removal is to improve visual quality so that images are clearer and easier to analyze. In this study, a mean filter is used for smoothing and a median filter is used for noise reduction. Combine mean and median filtering in this study is directly aligned with its emphasis on a pixel-domain, low-level analysis of convolution-based smoothing. The mask used has a size of 5, 9, 25, or 49 points as the kernel in the convolution mask operation to remove noise and smooth the image at the same time. The digital image processing application was created following the waterfall software development model stages. The BMP format was selected in this study primarily to ensure data integrity and experimental control. To measure the quality of the image produced after the smoothing process, the Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) standards are used. From the experimental results, the MSE values for mask sizes 5, 9, 25, and 49 are 12.96, 14.36, 14.72, and 16.80, respectively. Meanwhile, the PSNR values were 37, 36.56, 36.54, and 35.87, respectively. From the image quality results in the form of MSE and PSNR, it can be seen that the larger the mask size, the greater the MSE value, but the smaller the PSNR value. The smaller the PSNR value, the worse the image quality, and vice versa. This is supported by visual analysis, where more details of the original image are lost. However, the PSNR value is still in the range of 30-40 dB, which means the quality is still in the Good category. The quality is still acceptable with minimal distortion. The quality of the results is still very close to the original image. The highest image quality is found in mask 5.

## 1. Introduction

Digital images have become an important part of various fields of life, such as medical image processing [1], security surveillance [2], visual communication [3], and pattern recognition [4]. Digital images, are representations of visual information encoded in digital format, usually consisting of pixels arranged in a grid. Digital cameras, scanners, or computer algorithms are used to create these images. Red, green, and blue (RGB) channels are often used to represent numerical values that reflect color information in each pixel [5]. However, the quality of digital images is often compromised by noise, which can be generated by various factors, such as interference with the camera sensor, the shooting environment, or the digital data transmission process. This

noise can come from various sources, such as insensitive camera sensors, environmental interference, or digital data compression [6][7]. The presence of noise not only reduces the aesthetics of the image, but can also hinder image analysis and interpretation, especially in critical applications such as medical imaging or forensic analysis [6]. Various noise removal techniques have been developed to address this problem, but noise removal often results in the loss of important details or the appearance of new artifacts in the image. This is because noise can obscure important details in the image and reduce the clarity and accuracy of visual analysis. [8]. It is necessary to know some information's on the types of noise that corrupted the image to choose the desirable de-noising technique. So, selecting any technique that is utilized in the noisy image for the de-noising process is rely on the behavior of the noise [9]. There are several types of noise disturbances, namely Gaussian Noise, salt-and-pepper, and spackle noise [10] [11][12]. Gaussian noise is noise with a Gaussian probability distribution, often occurring in sensors due to heat or low lighting conditions. Salt-and-Pepper Noise is noise that appears as random white (salt) and black (pepper) pixels, usually caused by data transmission errors, and speckle noise is granular noise often found in images obtained from coherent imaging systems, such as ultrasound or radar.

To improve the quality of digital images, effective smoothing and noise reduction techniques are required. One method that is often used is the neighborhood operation [13][14][15], which utilizes the relationship between pixels in a specific area to improve the image. Neighborhood operations are one of the most widely used approaches in smoothing and noise removal. Neighborhood-based smoothing is one of the foundational techniques in digital image enhancement, where each pixel is updated based on the intensity values of its surrounding neighbors within a predefined window [10]. These methods typically use masks such as  $3 \times 3$ ,  $5 \times 5$ , or cross-shaped kernels to reduce noise while preserving the general structure of the image. Because of their simplicity and speed [8], neighborhood-based filters are widely used as baseline approaches in image preprocessing, segmentation, and real-time applications. In addition, neighborhood operations are not only intended to eliminate interference, but also to preserve important details in the image so that critical information is maintained.

However, the use of neighborhood operations also has challenges, such as adjusting the appropriate filter parameters to be effective in various types of noise and images. Neighborhood processing techniques in digital image processing have several drawbacks, including the need for high computational intensity because some algorithms that use this technique require substantial processing power and memory, especially for high-resolution images or when the size of the neighborhood kernel (mask) is large. This can result in long processing times and the appearance of blurring effects, where average-based spatial filters (such as mean filters), which are commonly used in neighborhood operations to remove noise, tend to blur edges and fine details in images. [10][16].

There are several common methods in neighborhood operations, namely median filter, mean filter, Gaussian filter [17] and low-pass filter. The Median Filter replaces pixel values with the median value of its neighbors. It is effective for removing impulse noise (salt-and-pepper noise) and can achieve the effect of filtering out noise, protecting details and image clarity. However, it is easy to cause discontinuous lines in the image. Mean Filter uses the average value of neighboring pixels to smooth the image, it is simple and fast in calculation and has a good filtering effect on Gaussian noise, but it can reduce sharpness, and it can not protect the image details after filtering the image. Gaussian Filter gives greater weight to pixels that are closer, resulting in smoother and more natural smoothing, but this method will flatten the edge because it is invalid to approach the edge. Low-Pass Filter reduces high frequencies (noise) while retaining the main elements of the image [18].

This method is important because improper noise removal processes can cause loss of detail or produce new artifacts in images. Therefore, research and development in smoothing and noise removal techniques, particularly using neighborhood operations, continues to evolve to support image quality improvement in various fields. It is hoped that this application of smoothing and noise reduction for improving digital image quality with neighborhood operations will be adaptive and effective in improving digital images into high-quality digital images that can be used for further analysis.

## 2. Method

### 2.1 Type and Approach of Research

This study is classified as quantitative and experimental research. The proposed approach implements neighborhood-based smoothing and noise reduction techniques in the spatial domain of digital images. Several neighborhood operations are experimentally applied and evaluated using quantitative image quality metrics such as MSE and PSNR. The research adopts a computational and comparative approach to assess the effectiveness of each method in enhancing digital image quality.

## 2.2 Object and Scope of Research

The scope and limitations of this research are as follows:

- a. The object of this research is digital images with the extension “BMP”.
- b. Digital “bmp” images have noise types such as salt and pepper, Gaussian, and speckle.
- c. Mean Filter is used for general smoothing.
- d. The Median Filter is used for noise removal.
- e. The mask used has a size of 5, 9, 25, or 49 points as the kernel in the convolution mask operation to remove noise and smooth the image at the same time. These mask sizes represent distinct levels of neighborhood aggregation, enabling a controlled evaluation of smoothing strength. The 5- and 9-point masks correspond to minimal and moderate smoothing, while the 25- and 49-point masks represent aggressive smoothing. The study focuses on fixed-size, deterministic convolution masks to ensure reproducibility and isolate the effect of neighborhood size without introducing additional parameters or adaptive behavior that could confound the analysis.

## 2.3 Data Collection Techniques

The method of image acquisition is by collecting sample images from image datasets. For generating noisy images is by adding artificial noise such as salt and pepper, gaussian and speckle.

## 2.4 Tools and Materials Used

This application was developed with the Desktop platform using Embarcadero Delphi 12.2 tools and the Delphi programming language. The desktop platform is an environment or system used to build applications that run locally on the user's computer, without requiring an internet connection for its main functions. Desktop applications usually have a graphical user interface (GUI) and are designed for specific operating systems such as Windows.

## 2.5 Research Procedures or Stages

### 2.5.1 Software Development Model

The Waterfall approach is often used in projects that have clearly defined specifications and requirements from the outset. Each stage in this model has an output that becomes the input for the next stage, so that the software development process runs systematically and is well documented. This study uses the Sommerville model. The stages in this method can be seen in Figure 1 [19].

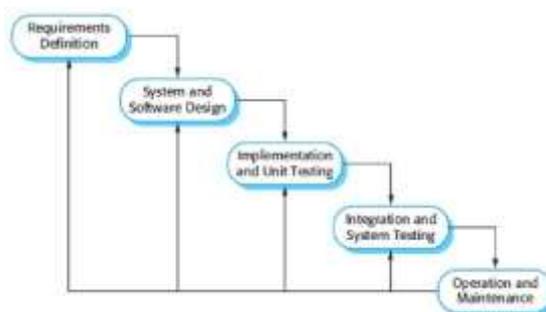


Fig 1. Waterfall paradigm

1. Requirement Definition

This stage begins with understanding or defining the needs and objectives of the software to be developed. The development team will study the needs and requirements for software development by determining the necessary features and functions. In this case, the needs and objectives of the software being developed are software capable of processing digital images to improve image quality by utilizing neighborhood operations, including smoothing and noise removal.

2. System and Software Design

After understanding the requirements, teams using the Waterfall Method design the architecture, design, and technical specifications of the software. The design also involves creating flowcharts and user interface designs.

3. Implementation and Unit Testing

Implementation involves writing program code and testing to ensure the quality of the software being developed. The tools used in software implementation are Embarcadero Delphi 12.2 and the Delphi programming language.

4. Integration and System Testing

After the program code is completed, testing is carried out to ensure that the software works properly. The result is software that is able to meet the requirements of the first stage.

5. Operation and Maintenance

The new maintenance process is implemented once the product has been released by the developer to users. The development team will continue to improve, update, and expand the software according to user needs. This stage not only keeps the device running smoothly, but also performs regular upgrades.

## 2.6 Data Analysis Techniques

In digital image processing, data analysis techniques have image quality error measurement standards, including MSE and PSNR[20]. MSE and PSNR are used to measure image quality. MSE (Mean Square Error) is the average square error value between the original image and the manipulated image. The MSE value is obtained by comparing the image value at the same pixel position with the difference in the original image pixel.

Peak Signal to Noise Ratio (PSNR) is used to measure the success rate and performance of a filtering method on an image. PSNR (Peak Signal to Noise Ratio) is a calculation that determines the value of an image. The magnitude of the MSE value that occurs in the image affects the PSNR value. PSNR is usually expressed in decibels (dB) in logarithmic form. The smaller the PSNR value, the worse the results obtained. Conversely, the greater the PSNR value, the better the results obtained. So the relationship between the MSE and PSNR values is that the smaller the PSNR value, the greater the MSE value.

Structural Similarity Index Measure (SSIM) was not considered in this study primarily due to methodological scope, consistency with classical image-processing evaluation, and experimental focus. The study emphasizes a pixel-domain, low-level analysis of convolution-based smoothing

The MSE formula is:

$$MSE = \frac{1}{MN} \sum_{x=1}^M \sum_{y=1}^N (S_{xy} - C_{xy})^2$$

Where :

- S<sub>xy</sub> = input image
- C<sub>xy</sub> = output image
- M = row size
- N = column size

PSNR formula :

$$PSNR = 10 \cdot \log_{10} \left( \frac{MAX^2}{MSE} \right)$$

Interpretation of image quality categories based on decibel values refers to standards ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) as well as based on research and academic journals [10][20] :

|            |   |
|------------|---|
| > 40 dB    | : excellent, almost indistinguishable from the original with the naked eye.   |
| 30 – 40 dB | : good, the quality is still acceptable, with minimal distortion. This is the general standard for video/image compression. |
| 20 – 30 dB | : poor, image or noise becomes clearly visible to the human eye.  |
| < 20 dB    | : unacceptable, the image is severely damaged and unusable.   |

### 3. Results and Discussion

#### 3.1 Presentation of Research Results

##### 3.1.1 Requirement Definition

At the requirements analysis stage, the requirements and objectives of the software being developed were defined, namely software capable of processing digital images to improve image quality by utilizing neighborhood operations, including smoothing and noise removal. From the results of this analysis, the steps described in the following algorithm were found to be in line with the research problem-solving method. Smoothing and Noise Removal algorithms:

1. Open Image and display the image on Canvas1
2. The image is represented in a 2 (two) dimensional matrix or array, assumed to be the Citra1 variable
3. Select the number of neighboring pixels used as a mask to remove noise, assumed as the variable Mask
4. Perform a neighborhood operation between Image1 and Mask by performing a convolution process using Mean Filter and Median Filter.
5. Display the convolution results that will smooth and remove noise in Image1 to Image2 as the result

##### 3.1.2 System and Software Design

At this stage, the architect, designer, and technical specifications of the software are carried out in the form of diagrams and interface designs.

###### 3.1.2.1 Perancangan Arsitektur Sistem

The architectural design of the Noise Reduction and Removal Application aims to build an efficient, modular, and easily developable system. This application was developed on a desktop platform using Embarcadero Delphi 12.2 tools and the Delphi programming.

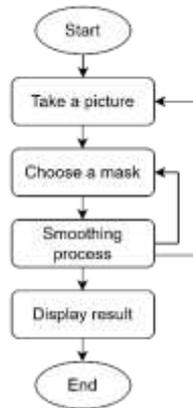
###### 3.1.2.2 Desain System

The design of noise reduction and smoothing applications aims to improve digital image quality by reducing unwanted visual disturbances. The design of noise reduction and smoothing applications consists of :

1. Image Input: Users can upload images from local files using the openpicturdialog component, which opens files with the “bmp” extension.
2. Image Selection: The “bmp” image type has an Interface Noise option that allows users to select the type of noise they want to remove (salt and pepper, Gaussian, speckle), displayed in TImage1.
3. Filtering Method Selection: Users can select the appropriate filtering method, Mean Filter for general smoothing, by selecting a mask with 5, 9, 25, or 49 points as the kernel in the convolution mask operation to remove noise and smooth the image. The components used can be ComboBox or RadioGroup or RadioButton.
4. Preview and Comparison: Displays the image before and after filtering side by side, displayed on TImage2
5. Export Results, save citra hasil filtering ke format “bmp” dengan menggunakan komponen savepicturdialog

###### 3.1.2.3 Flowchart Design

The application flowchart design is illustrated in Figure 2 as follows :



**Fig 2.** Program flowchart

The program will start, then take a “bmp” image and select Mask for 5, 9, 25, or 49 points. Next, the smoothing process will display the results of smoothing and noise removal based on the selected mask. From the smoothing process, you can take another image or select a mask and then process it for smoothing.

### 3.1.3 Implementation and Unit Testing

Implementation involves writing code in the Delphi programming language and testing to ensure the quality of the software built with Embarcadero Delphi 12.2 programming software, where code writing is divided into two groups, namely Project and Form control program.



**Fig 3.** Main program display

This display shows the Dashboard of the Smoothing and Noise Removal Application, where when you select Mask, the options 5 Points, 9 Points, 25 Points, and 49 Points will appear. The main program display is shown in figure 3.

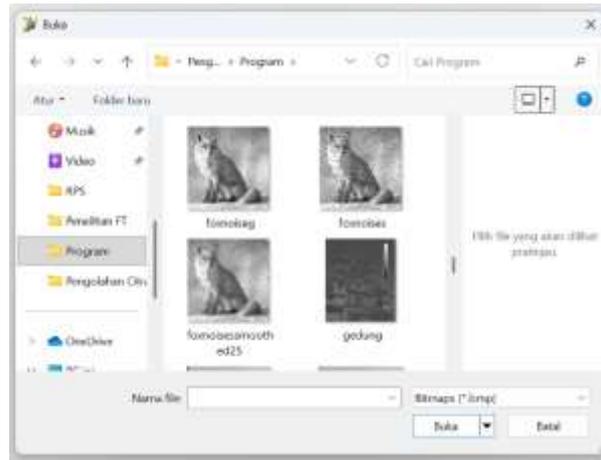


Fig 4. Image capture display

This display shows the “bmp” file that can be retrieved from the local folder. The display after retrieving the image is shown in Figure 4.



Fig 5. Display after image capture

This display appears after the “Capture Image” process. The display after capturing the image is shown in Figure 5.



Fig 6. Display of smoothing button press results

The display in Figure 6 shows two images that can be compared between the original image and the image resulting from the smoothing and noise removal process.

### Matrix Convolution Operation Results (Sample)

For a visual representation of how pixel values change, here is a sample 5x5 pixel matrix from the top left corner of the image for each operation.

Suppose that the original matrix is operated on with a 3 x 3 cross mask. The cross mask only uses the upper, lower, left, and right neighbors, not the diagonals. So for point (3,3), where the value for row 3 and column 3 is 140 in the original matrix, it has complete neighbors (5 points, not edges):

- Center : 140
- Top: 129
- Bottom: 128
- Left: 140
- Right: 132

The value after the convolution process is:

$$\frac{140 + 129 + 128 + 140 + 132}{5} = \frac{669}{5} = 133.8 \approx 134$$

All results of the matrix convolution operation can be seen in Table 1.

**Table 1.** Convolution Operation Results

| Mask                    | Image   | Matrix  |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
|-------------------------|---|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
|                         |   | <table border="1"> <tr><td>142</td><td>134</td><td>129</td><td>136</td><td>132</td></tr> <tr><td>137</td><td>136</td><td>129</td><td>134</td><td>126</td></tr> <tr><td>136</td><td>140</td><td>140</td><td>132</td><td>130</td></tr> <tr><td>141</td><td>137</td><td>128</td><td>133</td><td>130</td></tr> <tr><td>143</td><td>131</td><td>134</td><td>136</td><td>139</td></tr> </table> | 142 | 134 | 129 | 136 | 132 | 137 | 136 | 129 | 134 | 126 | 136 | 140 | 140 | 132 | 130 | 141 | 137 | 128 | 133 | 130 | 143 | 131 | 134 | 136 | 139 |
| 142                     | 134   | 129   | 136 | 132 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 137                     | 136   | 129   | 134 | 126 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 136                     | 140   | 140   | 132 | 130 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 141                     | 137   | 128   | 133 | 130 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 143                     | 131   | 134   | 136 | 139 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Mask 5<br>(cross 3 x 3) |  | <table border="1"> <tr><td>137</td><td>135</td><td>131</td><td>133</td><td>129</td></tr> <tr><td>137</td><td>135</td><td>134</td><td>131</td><td>130</td></tr> <tr><td>139</td><td>138</td><td>134</td><td>134</td><td>129</td></tr> <tr><td>139</td><td>135</td><td>134</td><td>132</td><td>134</td></tr> <tr><td>137</td><td>137</td><td>133</td><td>137</td><td>133</td></tr> </table> | 137 | 135 | 131 | 133 | 129 | 137 | 135 | 134 | 131 | 130 | 139 | 138 | 134 | 134 | 129 | 139 | 135 | 134 | 132 | 134 | 137 | 137 | 133 | 137 | 133 |
| 137                     | 135   | 131   | 133 | 129 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 137                     | 135   | 134   | 131 | 130 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 139                     | 138   | 134   | 134 | 129 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 139                     | 135   | 134   | 132 | 134 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 137                     | 137   | 133   | 137 | 133 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Mask 9<br>(box 3 x 3)   |  | <table border="1"> <tr><td>136</td><td>134</td><td>133</td><td>131</td><td>131</td></tr> <tr><td>137</td><td>136</td><td>134</td><td>132</td><td>131</td></tr> <tr><td>138</td><td>136</td><td>134</td><td>131</td><td>131</td></tr> <tr><td>137</td><td>137</td><td>135</td><td>134</td><td>132</td></tr> <tr><td>137</td><td>137</td><td>135</td><td>135</td><td>134</td></tr> </table> | 136 | 134 | 133 | 131 | 131 | 137 | 136 | 134 | 132 | 131 | 138 | 136 | 134 | 131 | 131 | 137 | 137 | 135 | 134 | 132 | 137 | 137 | 135 | 135 | 134 |
| 136                     | 134   | 133   | 131 | 131 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 137                     | 136   | 134   | 132 | 131 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 138                     | 136   | 134   | 131 | 131 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 137                     | 137   | 135   | 134 | 132 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 137                     | 137   | 135   | 135 | 134 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| Mask 25<br>(box 5 x 5)  |  | <table border="1"> <tr><td>136</td><td>136</td><td>134</td><td>132</td><td>131</td></tr> <tr><td>135</td><td>135</td><td>134</td><td>132</td><td>131</td></tr> <tr><td>135</td><td>135</td><td>135</td><td>133</td><td>131</td></tr> <tr><td>136</td><td>136</td><td>135</td><td>134</td><td>132</td></tr> <tr><td>137</td><td>136</td><td>136</td><td>134</td><td>134</td></tr> </table> | 136 | 136 | 134 | 132 | 131 | 135 | 135 | 134 | 132 | 131 | 135 | 135 | 135 | 133 | 131 | 136 | 136 | 135 | 134 | 132 | 137 | 136 | 136 | 134 | 134 |
| 136                     | 136   | 134   | 132 | 131 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 135                     | 135   | 134   | 132 | 131 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 135                     | 135   | 135   | 133 | 131 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 136                     | 136   | 135   | 134 | 132 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |
| 137                     | 136   | 136   | 134 | 134 |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |     |

Mask 49  
(box 7 x 7)



|     |     |     |     |     |
|-----|-----|-----|-----|-----|
| 135 | 134 | 134 | 133 | 132 |
| 135 | 134 | 134 | 133 | 132 |
| 135 | 135 | 134 | 133 | 132 |
| 135 | 135 | 135 | 134 | 133 |
| 136 | 136 | 135 | 135 | 134 |

### 3.1.4 Integration and System Testing

The program code was completed and then tested in stages to ensure that the software functioned properly. The result is software that meets the requirements of the first stage, where the Embarcadero Delphi 12.2 tools, when run, do not produce error messages and run well, producing a smoothing.exe executable file that can be run independently without the Embarcadero Delphi 12.2 tools on the Windows 11 operating system.

Table 2. Sytem Testing

| No. | Function Description     | Desirable Respon  | Fuctional Compatibiliy |
|-----|--------------------------|---|------------------------|
| 1.  | OpenPictureDialog        | Open the “bmp” image file located on the local drive.               | Successful             |
| 2.  | Memilih Mask             | Select the desired mask.  | Successful             |
| 3.  | OnClick Tombol Smoothing | Process the smoothing and noise removal to produce the final image. | Successful             |
| 4.  | SavePictureDialog        | Save the smoothed and noise-removed file as a “bmp” file.           | Successful             |

#### 3.1.4.1 Image Quality Testing

Image quality testing in this study uses MSE and PSNR measures. The following are the MSE and PSNR calculations from the original image with the mask 5 image on the fox image above.

$$MSE = \frac{1}{MN} \sum_{x=1}^M \sum_{y=1}^N (S_{xy} - C_{xy})^2$$

$$MSE = \frac{(142 - 137)^2 + (134 - 135)^2 + (129 - 131)^2 + \dots + (139 - 133)^2}{5 \times 5} = \frac{324}{25} = 12,96$$

$$PSNR = 10 \cdot \log_{10} \left( \frac{MAX^2}{MSE} \right)$$

For 8-bit images (maximum value = 255)

$$PSNR = 10 \cdot \log_{10} \left( \frac{255^2}{12,96} \right) = 37$$

The same calculation can be performed for other masks and is shown in Table 3.

## 3.2 Analysis of Findings

### 3.2.1 Visual Results

The results of convolution operations with various masks produce different visual images, namely:

1. Mask 5 (Cross 3 x 3): Provides the most subtle smoothing. Image edge details (such as fox fur) remain fairly sharp, but minor noise begins to be reduced.
2. Mask 9 (3 x 3): Standard smoothing. The image will look slightly more blurred than the original. Small noise spots (if present in the original image) will fade.
3. Mask 25 (5 x 5): The image will look noticeably more blurred. Fine details such as fur texture will be lost and blend together. This is effective for larger noise but sacrifices detail.
4. Mask 49 (7 x 7): The image will become very blurry (very strong blurring effect). The fox may only be visible as a gradient silhouette without clear fur texture. This is only used if the image has very severe noise.

The larger the Mask (Kernel) size, the stronger the smoothing (blur) effect, which means it is more effective at removing noise, but more of the original image detail is lost.

### 3.2.2 Image Quality Results

**Table 3.** MSE and PSNR Value

| Mask | MSE   | PSNR  |
|------|-------|-------|
| 5    | 12,96 | 37    |
| 9    | 14,36 | 36,56 |
| 25   | 14,72 | 36,45 |
| 49   | 16,80 | 35,87 |

From the image quality results in the form of MSE and PSNR, it can be seen that the larger the mask size, the larger the MSE size, but the smaller the PSNR size. The smaller the PSNR value, the worse the image quality and vice versa. This is supported by visual analysis, where more details of the original image are lost. However, the PSNR value is still in the range of 30-40 dB, which means that the quality is still in the Good category. This values refers to standards ITU-T (International Telecommunication Union - Telecommunication Standardization Sector) as well as based on research and academic journals [10][20]. The quality is still acceptable with minimal distortion. The quality of the results is still very close to the original image. The highest image quality is found in mask 5.

### 3.3 Implications of the Results

This research provides important contributions both in practical implementation and theoretical understanding of image smoothing using neighborhood-based masks of varying sizes. Practically, the system developed can be applied as an effective pre-processing method in computer vision pipelines, medical imaging, satellite image analysis, and low-light photography, where noise reduction is required without sacrificing essential image details.

The evaluation of multiple mask sizes and their impact on MSE and PSNR enriches theoretical knowledge by validating the trade-off between noise suppression and detail preservation, confirming that smaller masks such as Mask 5 offer the optimal balance between smoothing and fidelity. This contributes to model development by providing empirical evidence on how filter size influences image quality, supporting the refinement of low-level processing algorithms.

The findings also offer clear benefits to stakeholders such as engineers, researchers, industry practitioners, and end users: engineers gain a lightweight and computationally efficient filtering option, researchers obtain baseline metrics for algorithm comparison, and industries such as healthcare, security, and mobile imaging can improve the reliability and clarity of their image-processing systems. From a societal perspective, improved image quality enhances the accuracy of systems used in diagnostics, surveillance, mapping, and documentation, ultimately leading to better decision-making.

### 3.4 Limitations of the Study

The dataset used was limited in size, diversity, and quality, consisting primarily of small matrix samples rather than a wide range of real-world images with varying lighting conditions, textures, resolutions, and noise types. The study is based on a limited number of test images and noise realizations, which constrains the statistical robustness of the evaluation. With a small sample size, performance metrics such as MSE and PSNR are more susceptible to image-specific characteristics, including local texture distribution, edge density, and noise placement. Under these conditions, the 5-point mask may appear to perform best because it introduces minimal smoothing, thereby preserving pixel intensity values closer to the original image for this specific dataset. As a result, the behavior of different mask sizes may not fully represent performance on large, complex, or high-resolution datasets. The system itself has inherent limitations, including reliance on a fixed platform and the use of only basic neighborhood operations without integrating more advanced or adaptive filtering features.

The study focused solely on quantitative metrics such as MSE and PSNR, which, although widely accepted, do not always reflect human perceptual quality. The evaluation also did not incorporate alternative assessment methods, such as SSIM, visual saliency metrics, or subjective human evaluation.

To overcome these limitations, future research should expand the dataset to include more diverse image types and noise conditions, enabling a more robust assessment of mask performance. The development of smoothing and noise removal techniques in digital images using neighborhood operations continues to undergo innovation to improve image quality more effectively. Here are some of the latest research developments that can be found in the use of other methods, including: Adaptive Neighborhood Filtering, Machine Learning-Based Approaches, Non-Local Means (NLM) Filtering, Hybrid Filtering Techniques and other methods. Future work should integrate perceptual quality assessment tools and combine quantitative and qualitative approaches for a more holistic evaluation

#### 4. Conclusion

Based on the results of the research and description in this research discussion are:

- a. Produced a desktop-based Digital Image Processing Application with Embarcadero Delphi 12.2 tools.
- b. The application successfully improved Digital Images by smoothing and removing noise in digital images.
- c. Successfully implementing the Mean Filter smoothing method and noise reduction with the Median Filter using convolution operations with masks of 5, 9, 25, and 49 pixels, resulting in a desktop-based application
- d. Through the application of multiple convolution masks and the evaluation of their outputs using MSE and PSNR, the study demonstrated that mask size plays a crucial role in balancing noise reduction and detail retention. The findings show that smaller masks, particularly the 3×3 cross mask (Mask 5), produce the highest image fidelity, while larger masks increase smoothing at the cost of losing finer details.

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#### Declarations

**Author contribution.** The authors served as the researcher. The second author is responsible for writing manuscript

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