Grayscale Image Quality Analysis Result of Noises Reduction using Adaptive Fuzzy Filter (AFF) and Spatial Median Filter (SMF) Against Image Depth Variations

Irpan Adiputra Pardosi and Ali Akbar Lubis

Department of Computer Science, STMIK Mikroskil, Medan, North Sumatera, Indonesia
E-mail: irpan@mikroskil.ac.id and ali.akbar@mikroskil.ac.id

Abstract. Removing salt and pepper noise in the image will have an impact on information in the image, with a greater percentage of noise, the changes in the results image will also be large, this is very likely different from the types of grayscale images with different depths such as 8, 16 and 24 bit. The percentage of noise that will be used starts from 45%, this is based on previous studies which reveal the ability of noise reduction algorithms to be able to work a maximum of below 20%, so that it needs to be studied more deeply the performance of the algorithm and its impact on images with greater noise. From the results of previous research studies, the Spatial Median Filter algorithm and Adaptive Fuzzy Filter algorithm can reduce noise with the maximum percentage of noise below 45% in the 8 Bit image, but leave some noise after being reduced. The test results on grayscale image obtained the average overall results quality Adaptive Fuzzy Filter algorithm is better than Spatial Median Filter in terms of image quality using PSNR but the diversity of information is even more reduced compared to the SMF algorithm referring to the entropy shannon value

1. Introduction
Noise reduction will improving image quality results for information in the image including changing, this is one of the challenges in image processing [1][2]. Many noises solve in image processing mostly about salt reduction on the image that has decreased in quality due to noise in the image causes the object in the image to be unclear [3]. Changes in information on the reduced image have an impact it changes that are too large will certainly cause a lot of information lost in the image, besides that the quality of the reduced image becomes something to be considered with large noise (≥ 45%) [3]. Measurement of changes in the reduced image will be compared to the original image before and after the reduction process is carried out, with the aim to obtain the percentage change in information in the image. In general, the image depth is 8 bits, 16 bits and 24 bits, a more in-depth study is needed to analyze the impact of noise reduction on varying image depths, so the use of algorithms is exactly the type of image used.

Some of the research algorithms that have been done to reduce image noise include using Adaptive Fuzzy Filter algorithm which can eliminate gaussian noise and salt pepper[3], besides that there are also comparing Spatial Median Filter and Adaptive Noise Reduction algorithms for reduce noise salt and pepper with the conclusion that the Spatial Median Filter algorithm reduces noise better for noise above 20% but is not tested up to the maximum noise percentage, while Adaptive Noise Reduction
can work more optimally with the amount of noise below 10% [4][5]. Based on the references, the above methods used for noise reduction of salt and pepper have not analyzed the impact of noise reduction on changes in information on the reduced image but it has been proven to eliminate noise salt, so that studies and analyzes are needed to be more in depth so that impacts are expected noise reduction to image quality and diversity of information in it.

In general, this study was designed as follows: Initially the preparation of test data included grayscale images with 8bit, 16bit and 24 bit depth. Then, the noise reduction process for each image is carried out using both algorithms. Furthermore, analysis of noise reduction results will be carried out in terms of the color changes as information and a comparison will be made to test the best quality between the Spatial Median Filter and Adaptive Fuzzy Filter. Analysis will be carried out to get the best algorithmic algorithm combination with type into the image, which is measured both in terms of data (information) and the quality of the reduced image.

Utilization of salt and pepper noise reduction technology implemented in an application as a testing medium will provide benefits such as understanding the impact of noise reduction on color combinations on the image, the relationship of noise reduction with the depth of image, and the impact of image changes with its quality. In addition, a more in-depth study of the application of algorithms with the right type of image depth will also be obtained. The results of this study are also expected to be a reference for research on noise reduction, especially salt and pepper so that further studies that will be carried out can be more profound and widespread.

2. Research Method

Tests that will be used in this study include testing the image information vulnerability, the size of the results image and the quality of the results image.

2.1. Problem Analysis

The noise removal process in the image has several problems, including the object in the results of the image must still be able to be seen with good quality, and the diversity of information the results of the image is not much different after the noise is reduced besides that the process must be the same between the initial image and the results with the bit depth the same so that the impact on image depth varies.

2.2. Process Analysis

In this section, the process flow of the AFF (Adaptive Fuzzy Filter) algorithm and the SMF (Spatial Median Filter) algorithm will be explained separately.

2.2.1. AFF (Adaptive Fuzzy Filter) method consist of 4 main parts: fuzzy rank selection, fuzzy weighted, fuzzy neural network (FNN) and softswitching. This technic implement to signal where mostly dimension convertion to vector. FNN Filter and switching fuzzy filter can’t adaptation with environment, to improved it need use neural network technic. Given operating window X with 3x3, calculate difference $\Delta x_i = x_i^p - x_i^t$ ($t = 1,...,8$), $\Delta x'_j = x_i^p - x'_j$ ($j = 1,...,16$) between $x_i$ and its adjacent pixels in X, $x_i^p$ and 16 adjacent outside pixels of X, respectively. Using $\{\Delta x_i\}$ and $\{\Delta x'_j\}$, author in [6] gives fuzzy inference rules as [6]. The main aim of neuro-fuzzy filter is to determine adjusted value $\Delta y$ for the central gray level $x_i^p$. Thus, the output y of the filter is calculated as follows:

$$y = x_i^p + \Delta y \Delta y$$

is adaptively adjusted with a FNN, whose architecture five layer feedforward network. The inputs are $\Delta x_i (i = 1,...,8)$, $\Delta x'_j (j = 1,...,16)$ Fuzzification layer consists of four parts, whose first and third are equipped with the membership function $\tilde{\mu}_p$ of fuzzy set “positively large”.

The corresponding outputs are defined as follows:

- **Neuro-Fuzzy Filter**
And the second and fourth parts with the membership function \( L_n \) of fuzzy set “negatively large” have the following Outputs, respectively:

\[
O^{(3)}_{2i} = \tilde{L}_n(\Delta x_i) \quad (i = 1, \ldots, 8) \tag{3}
\]

\[
O^{(5)}_{2j} = \tilde{L}_n(\Delta x_j) \quad (j = 1, \ldots, 16) \tag{4}
\]

Thus, in the inference layer I, the output of the \( k \)-th part is as follows:

\[
O^{(3)}_{k} = \bigvee_{i=1}^{8} \left( O^{(2)}_{ki} \cdot w^{k}_{ki} \right) \quad (k = 1, 2) \tag{5}
\]

\[
O^{(4)}_{k} = \bigvee_{j=1}^{16} \left( O^{(2)}_{kj} \cdot w^{k}_{kj} \right) \quad (k = 3, 4) \tag{6}
\]

The outputs of two units in the inference layer II are:

\[
O^{(5)}_{1} = \left( \bigwedge_{i=1}^{8} \left( O^{(3)}_{1i} \right) \right) \land \left( \bigwedge_{j=1}^{16} \left( O^{(3)}_{3j} \right) \right) \tag{7}
\]

\[
O^{(6)}_{2} = \left( \bigwedge_{i=1}^{8} \left( O^{(3)}_{2i} \right) \right) \land \left( \bigwedge_{j=1}^{16} \left( O^{(3)}_{4j} \right) \right) \tag{8}
\]

The output of the FNN is as \( \Delta y = (L - 1) \).

\[
S_{\lambda_{m}} \left( (L - 1) \left( O^{(4)}_{1} - O^{(4)}_{2} \right) \right) \cdot \text{sign} \left( O^{(4)}_{1} - O^{(4)}_{2} \right).
\]

Thus, the FNN filter may be represented as

\[
Y_{fn}(X) = x_p + \Delta y.
\]

In [7], the connection weights \( w^{k}_{ti} \), \( w^{k}_{ij} \) and fuzzy set \( \tilde{S}_{m} \) and consequently its complement are determined by genetic algorithm. The filter \( Y_{fn} \) can remove the high intensity noise.

Further it may well acclimatize itself to the environmental variation. We can guarantee good performance of the filter in different probability impulse noises. If the fuzzy operator pair (max, min) is not directly given, but selected rationally to the problems related \([8]\), we can improve the performance of \( Y_{fn} \) further. However, in application the filtering performance of neuro-fuzzy filter will be very poor if noise is not impulse, but a mixture of several noises, such as impulse and Gaussian noises. Further, many problems about FNN related to neuro-fuzzy filter remain to be solved. For example,:

\[\text{Selection Type FNN Filter}\]

Assume that the values of gray levels for two-dimensional image \( F = \{ F(t_1, t_2), \ \text{where} \ t_1, t_2 \leq N \} \) belong to \([0, L - 1]\).
\( \forall (t_1, t_2) \in \{0,1,\ldots,N\}^2, F(t_1, t_2) \in [0, L - 1] \). Introduce fuzzy partition of \([0, L - 1]\) to describe image \( F \) with fuzzy sets \( \tilde{G}_L, \ldots, \tilde{G}_{k_0} \). For example, let these fuzzy sets be “dark(\( \tilde{D}_a \))”, “dark(\( \tilde{D}_r \))”, “medium(\( \tilde{M}_m \))”, “brighter(\( \tilde{B}_{mr} \))”, “bright(\( \tilde{B}_r \))”, respectively, which are shown in Figure 2.

In order to suppress impulse noise, introduce a mean fuzzy set \( \text{Trap} \), whose form may be represented as a trapezoidal fuzzy number as Fig. 3. By Gray level fuzzy sets and mean fuzzy set a selection type FNN may be developed. Let operating window \( X = \{x_1, \ldots, x_p, \ldots, x_d\} \), where \( x_p \) is the gray level of central pixel, that is, \( x_p = F(t_1, t_2) \). The topological structure of selection type FNN is shown in Fig. 4, and I/O relationship is expressed as follows:

\[
\begin{align*}
        m^k(X) &= \frac{\sum_{j=1}^d x_j \tilde{G}_k(x_j)}{\sum_{j=1}^d \tilde{G}_k(x_j)}, \quad m(X) = \frac{\sum_{j=1}^d x_j \text{Trap}(x_j)}{\sum_{j=1}^d \text{Trap}(x_j)} \\
        A_f &= m^k(X), \text{dimana} \\
        k' &= \max_{k_1} \{ k_1 : |m(X) - m^k(X)| = \min_k \{|m(X) - m^k(X)|\} \}.
\end{align*}
\]
If $F$ is a noise-free image, the gray degree values $x_1, \ldots, x_p, \ldots, x_d$ in window $X$ are approximately equal, that is $x_1 \approx \cdots \approx x_p \approx \cdots \approx x_d \approx m(X)$. So if $u$ is output variable, and $v = |x_p - m(X)|$ is input variable, then we can obtain the following Mamdani inference rules [9]:

IF $v$ is "small" THEN $u$ is $\tilde{x}_p$;

IF $v$ is "large" THEN $u$ is $\overline{A}_f$.

Where $\tilde{x}_p$, $\overline{A}_f$ mean the fuzzifications of $x_p$, $A_f$. Dan $x_p \in \ker(\tilde{x}_p)$, $A_f \in \ker(\overline{A}_f)$. On gray level set $[0, L - 1]$ define $\tilde{S} = "small", \overline{L} = "large"$.

\[
B_f = \frac{x_p \tilde{S}(u) + \overline{A}_f \overline{L}(u)}{\tilde{S}(u) + \overline{L}(u)} = \frac{x_p \tilde{S}(|x_p - m(X)|) + \overline{A}_f \overline{L}(|x_p - m(X)|)}{\tilde{S}(|x_p - m(X)|) + \overline{L}(|x_p - m(X)|)},
\]

Equations (9) and (10) constitute the I/O relationship of a selection type FNN filter, whose structure is shown as Fig. 5. To seek optimal selection type FNN filter, it suffices to design learning algorithms for the parameters of selection type FNN and inference type FNN, respectively. The learning algorithm for selection type FNN aims at determining the partition of gray level set $[0, L - 1]$, that is, determining the value of $k_0$, fuzzy member $\tilde{G}_{k_0}$ in fuzzy particion. The algorithm can be described as follows:

i. To a n-bit digital image, the variation not exceeding $2^{n-4}$ in gray level of image will not lead to obvious visual changes [10]. So, partition $[0, L - 1]$ into $2^{n-4}$ identical parts.

ii. Seek higher concentration area of gray levels of image $F$: Calculate the number $\Gamma_k$ dari $F$ belonging to $I_k \triangleq \left[(k - 1)L/(2^{n-4}), (kL/(2^{n-4}))\right] (k = 1, \ldots, 2^{n-4})$. And discriminate $\Gamma_k \geq \eta$? if yes, $I_k$ is called concentration area of gray levels of $F$, where $\eta$ is a given constant corresponding to image $F$.

iii. Determine fuzzy partition of $[0, L - 1]$ be the number of concentration areas of gray levels. And they are $I_{k_1}, \ldots, I_{k_n}$. Thus, fuzzy numbers $\tilde{G}_{k_1}, \ldots, \tilde{G}_{k_n}$ may be constructed.

In the definition of mean fuzzy set for selection type FNN, parameter $l$ is assumed to be about 3, and selection standard value is $m(X)$, we can obtain good results for removing impulse noise. Based on the learning algorithm for selection type FNN, by back propagate learning algorithm about $s_{11}, s_{22}$, inference FNN can be constructed. Thus, selection type FNN filter may be determined. By [9] we can obtain restoration images with high quality by selection type FNN filter from noise images degraded by high or low probability impulse noises. Further, if the noise is hybrid, the good filtering performance of the filter can be also ensured. Since general fuzzy systems may be realized by some FNN [11], it is a main subjects for future research that some rational fuzzy rules should be developed, and a simple FNN easy to realize is employed to remove noises. Many elementary problems related to the subject are solved in [12].

### 2.2.2. Spatial Median Filter (SMF)

The following is the basic algorithm determining he Spatial Median of a set of points, $x_1, \ldots, x_N$:

1. For each vector $x$, compute $S$, which is a set of the sum of the spatial depths from $x$ to every other vector.
2. Find the maximum spatial depth of this set, $S_{\text{max}}$.
3. $S_{\text{max}}$ is the Spatial Median of the set of points.
The spatial depth between a point and set of points is defined by J. Church [13] for future research that some rational fuzzy rules should be developed, and a simple FNN easy to realize is employed to remove noises. Many elementary problems related to the subject are solved in [12].

3. Result
Algorithm implementation with C# programming, some of capture result show on figure below. This test was carried out to measure the quality level of the image after noise reduction for the dataset of grayscale BMP 8, 16 and 24 bit images with noise percentage 45%, 55%, 65% and 75% by measuring based on PSNR value from the results image will description on below:

### Table 1. Quality of Result Reduction Noise of grayscale image on bmp 24 bit

| Images    | PSNR- AFF | PSNR- SMF | PSNR- AFF | PSNR- SMF | PSNR- AFF | PSNR- SMF | PSNR- AFF | PSNR- SMF |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Image01.bmp | 20.20770  | 20.58638  | 19.81405  | 20.08105  | 19.59805  | 19.76879  | 19.12153  | 19.32801  |
| Image02.bmp | 14.51758  | 15.13259  | 13.86801  | 14.29201  | 13.95378  | 14.18585  | 13.52623  | 13.59999  |
| Image03.bmp | 17.06620  | 17.08088  | 16.58689  | 17.34640  | 19.20669  | 16.57507  | 20.07172  | 17.56616  |
| Image04.bmp | 35.28816  | 32.58382  | 35.26313  | 32.14437  | 36.85197  | 32.56929  | 36.81388  | 32.36759  |
| Image05.bmp | 12.94146  | 13.69398  | 12.21428  | 12.90298  | 11.57513  | 12.19283  | 11.10675  | 11.67064  |
| Average   | 20.00422  | 19.81553  | 19.54927  | 19.35336  | 20.23712  | 19.05837  | 20.12802  | 18.90588  |

From table 1 on above, it can be seen that the image quality results in all noise percentage based on the PSNR value of the overall image, the AFF algorithm is better than the SMF.

### Table 2. Image Information Reducing Result of grayscale image on bmp bmp 24 bits

| Images    | Shannon- AFF | Shannon- SMF | Shannon- AFF | Shannon- SMF | Shannon- AFF | Shannon- SMF | Shannon- AFF | Shannon- SMF |
|-----------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|--------------|
| Image01.bmp | 0.06398      | 0.00766      | 0.06464      | 0.00678      | 0.49972      | 0.08541      | 0.49919      | 0.08897      |
| Image02.bmp | 0.18877      | 0.22457      | 0.20602      | 0.25580      | 0.11813      | 0.04724      | 0.13475      | 0.07681      |
| Image03.bmp | 0.11463      | 0.02650      | 0.11623      | 0.03762      | 0.74704      | 0.11456      | 0.74800      | 0.09322      |
| Image04.bmp | 0.10340      | 0.00055      | 0.10135      | 0.01395      | 0.05525      | 0.09744      | 0.05499      | 0.08759      |
| Image05.bmp | 0.24207      | 0.15684      | 0.25589      | 0.18428      | 0.74024      | 0.26917      | 0.74979      | 0.30088      |
| Average   | 0.14257      | 0.08322      | 0.14883      | 0.09968      | 0.43208      | 0.12276      | 0.43735      | 0.12949      |

In table 2 show different results with table 1, which are seen for the diversity of information in the results image after the reduction process, with the AFF algorithm the image results experience a greater loss of information than the SMF, so the difference in information lost after reduce noise with the SMF is better than AFF.

### Table 3. Quality of Result Reduction Noise on grayscale image on bmp 16 bit

| Images    | PSNR- AFF | PSNR- SMF | PSNR- AFF | PSNR- SMF | PSNR- AFF | PSNR- SMF | PSNR- AFF | PSNR- SMF |
|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| Image01.bmp | 20.20770  | 20.58638  | 19.81405  | 20.08105  | 19.59805  | 19.76879  | 19.12153  | 19.32801  |
| Image02.bmp | 14.51758  | 15.13259  | 13.86801  | 14.29201  | 13.95378  | 14.18585  | 13.52623  | 13.59999  |
| Image03.bmp | 17.06620  | 17.08088  | 16.58689  | 17.34640  | 19.20669  | 16.57507  | 20.07172  | 17.56616  |
| Image04.bmp | 35.28816  | 32.58382  | 35.26313  | 32.14437  | 36.85197  | 32.56929  | 36.81388  | 32.36759  |
| Image05.bmp | 12.94146  | 13.69398  | 12.21428  | 12.90298  | 11.57513  | 12.19283  | 11.10675  | 11.67064  |
| Average   | 20.00422  | 19.81553  | 19.54927  | 19.35336  | 20.23712  | 19.05837  | 20.12802  | 18.90588  |
From table 3 on above, it can be seen that the image quality results in all noise percentage based on the PSNR value of the overall image, the AFF algorithm is better than the SMF.

Table 4. Image Information Reducing Result of grayscale image on bmp bmp 16 bit

| Images   | 45% | 55% | 65% | 75% |
|----------|-----|-----|-----|-----|
| Shannon-AFF | Shannon-SMF | Shannon-AFF | Shannon-SMF | Shannon-AFF | Shannon-SMF | Shannon-AFF | Shannon-SMF |
| Image01.bmp | 0.06398 | 0.00766 | 0.06464 | 0.00678 | 2.44010 | 1.33336 | 1.33016 |
| Image02.bmp | 0.18877 | 0.22457 | 0.20602 | 0.25580 | 0.24154 | 0.29972 | 0.25442 |
| Image03.bmp | 0.11463 | 0.02650 | 0.11623 | 0.03762 | 2.22652 | 1.21144 | 1.20593 |
| Image04.bmp | 0.10340 | 0.00055 | 0.10135 | 0.01395 | 1.99748 | 1.10641 | 1.13024 |
| Image05.bmp | 0.24207 | 0.15684 | 0.25589 | 0.18428 | 1.39312 | 0.82987 | 1.39981 |
| Average   | 0.14257 | 0.08322 | 0.14883 | 0.09968 | 1.65975 | 0.95616 | 0.85617 |

In table 4 show the diversity of information in the results image after the reduction process, with the AFF algorithm the image results experience a greater loss of information than the SMF, so the difference in information lost after reduce noise with the SMF is better than AFF.

Table 5. Quality of Result Reduction Noise on grayscale image on bmp 8 bit

| Images   | 45% | 55% | 65% | 75% |
|----------|-----|-----|-----|-----|
| PSNR-AFF | PSNR-SMF | PSNR-AFF | PSNR-SMF | PSNR-AFF | PSNR-SMF | PSNR-AFF | PSNR-SMF |
| Image01.bmp | 20.71094 | 20.80728 | 20.25602 | 20.23705 | 19.61152 | 19.74339 | 19.08229 | 19.18006 |
| Image02.bmp | 15.00753 | 15.49107 | 14.45603 | 14.80452 | 13.89686 | 14.06965 | 13.54569 | 13.70508 |
| Image03.bmp | 21.16425 | 20.21373 | 20.48368 | 18.52757 | 20.10835 | 17.82852 | 19.34934 | 16.51471 |
| Image04.bmp | 36.89708 | 33.68349 | 36.89488 | 33.30127 | 36.82826 | 32.51045 | 36.81537 | 32.08427 |
| Image05.bmp | 12.88807 | 13.62594 | 12.18474 | 12.86530 | 11.59573 | 12.24652 | 11.08229 | 11.64728 |
| Average   | 21.33357 | 20.76430 | 20.85507 | 19.94714 | 20.40814 | 19.27971 | 19.97500 | 18.62628 |

From table 5 on above, it can be seen that the image quality results in all noise percentage based on the PSNR value of the overall image, and still the AFF algorithm is better than the SMF but more closely.

Table 6. Image Information Reducing Result of grayscale image on bmp bmp 8 bit

| Images   | 45% | 55% | 65% | 75% |
|----------|-----|-----|-----|-----|
| Shannon-AFF | Shannon-SMF | Shannon-AFF | Shannon-SMF | Shannon-AFF | Shannon-SMF | Shannon-AFF | Shannon-SMF |
| Image01.bmp | 0.49866 | 0.07613 | 0.50101 | 0.07381 | 0.50046 | 0.08167 | 0.49878 | 0.08526 |
| Image02.bmp | 0.08679 | 0.01965 | 0.10040 | 0.01261 | 0.11949 | 0.05184 | 0.13290 | 0.07432 |
| Image03.bmp | 0.75633 | 0.06983 | 0.75279 | 0.08309 | 0.74789 | 0.11857 | 0.74104 | 0.09403 |
| Image04.bmp | 0.05680 | 0.10828 | 0.05696 | 0.10083 | 0.05426 | 0.09274 | 0.05523 | 0.08260 |
| Image05.bmp | 0.71579 | 0.20684 | 0.73012 | 0.24894 | 0.73749 | 0.26764 | 0.74940 | 0.29238 |
| Rata-rata | 0.42287 | 0.09615 | 0.42826 | 0.10385 | 0.43192 | 0.12249 | 0.43547 | 0.12572 |
In table 6 show the diversity of information in the results image after the reduction process, with the AFF algorithm the image results experience a greater loss of information than the SMF, so the difference in information lost after reduce noise with the SMF is better than AFF.

4. Conclusions and future work
From the results of the tests that have been carried out, it can be concluded as follows; The average image grayscale quality results from noise reduction with AFF algorithms have better quality than the SMF algorithm. Difference of changes in the diversity of information with the SMF algorithm are smaller than the AFF algorithm with the best results 0.083 in image depth 16 and 24 Bit and changes in the image of the results with the AFF algorithm have the greatest impact of change for all depths of the result.
The future work for further system development are using more datasets and datasets that already have noise in accordance with the percentage of noise that will be tested or using a method for adding noise and applying other algorithms that can eliminate noise with image quality above 40 dB

Acknowledgments
This work was supported by the Ministry of Research, Technology and Higher Education Indonesia

References
[1] J. R. Tang and N. A. M. Isa, “An Adaptive Fuzzy Contrast Enhancement Algorithm with Details Preserving,” J. ICT Res. Appl., vol. 8, no. 2, pp. 126–140, 2014.
[2] A. K. Gupta, “Low Contrast Image Enhancement Technique By Using Fuzzy Method,” vol. 4, no. 2, pp. 518–526, 2016.
[3] M. Pitchammal, S. S. Nisha, and M. M. Sathik, “Noise Reduction in MRI Neck Image Using Adaptive Fuzzy Filter in Contourlet Transform,” vol. 6, no. 3, pp. 2478–2484, 2016.
[4] E. Lotfi, “An Adaptive Fuzzy Filter for Gaussian Noise Reduction using Image Histogram Estimation,” no. October, pp. 1–4, 2013.
[5] I. Pardosi and J. T. Informatika, “Salt and Pepper Noise Removal dengan Spatial Median Filter dan Adaptive Noise Reduction,” vol. 17, no. 2, pp. 127–136, 2016.
[6] Y. S. Choi and R. Krishnapuram, “A robust approach to image enhancement based on fuzzy logic,” IEEE Trans. Image Process., vol. 6, no. 6, pp. 808–25, 1997.
[7] F. Russo, “Hybrid neuro-fuzzy " lter for impulse noise removal,” vol. 32, no. November 1998, 1999.
[8] F. Russo and G. Ramponi, “Nonlinear fuzzy operators for image processing,” Signal Processing, vol. 38, no. 3, pp. 429–440, 1994.
[9] P. Liu, “Analysis of approximation of continuous fuzzy functions by multivariate fuzzy polynomials,” Fuzzy Sets Syst., vol. 127, no. 3, pp. 299–313, 2002.
[10] Y. H. Kuo, C. S. Lee, and C. L. Chen, “High-stability AWFM filter for signal restoration and its hardware design,” Fuzzy Sets Syst., vol. 114, no. 2, pp. 185–202, 2000.
[11] P. Liu, “Analyses for L p … l † -norm approximation capability of generalized Mamdani fuzzy systems q,” Inf. Sci. (Ny.)., vol. 138, pp. 195–210, 2001.
[12] P. & L. X. Liu, “Image restoration techniques based on fuzzy neural networks,” vol. 45, no. 4, 2002.
[13] J. C. Church, Y. Chen, and S. V. Rice, “A Spatial Median Filter for noise removal in digital images,” Conf. Proc. - IEEE SOUTHEASTCON, pp. 618–623, 2008.
[14] E. J. Leavline, D. A. Antony, and G. Singh, “Salt and Pepper Noise Detection and Removal in Gray Scale Images : An Experimental Analysis,” vol. 6, no. 5, pp. 343–352, 2013.
[15] T. Gebreyohannes and D. Kim, “Adaptive Noise Reduction Scheme for Salt and Pepper,” Arxiv Prepr. arXiv1201.2050, 2012.