Jurnal Fisika 13 (2) (2023) 59-68

Jurnal Fisika

https://journal.unnes.ac.id/nju/index.php/jf/index

Application of Pyramidal Decomposition to Improve Digital Radiography Image Quality

Rudi Setiawan[1], Susilo[2]

[1]Radiodiagnostic and Radiotherapy Engineering, Sekolah Tinggi Ilmu Kesehatan An Nasher, Cirebon, Indonesia
[2]Biomedical Engineering, Universitas Dian Nuswantoro, Semarang, Indonesia

Article Info

Article History:

Received:
28 September 2023

Accepted:
28 December 2023

Published:
29 December 2023

Keywords:
pyramidal decomposition, digital radiography, MSE, PSNR

Abstract

As an effort to create innovation in the world of radiography, it is necessary to develop technology in software. This effort is to improve image quality by using pyramidal decomposition. This digital image decomposition is referred to as pyramid decomposition. The original image is decomposed into several frequency bands, repeatedly divided into high-pass components and low-pass components. The high-pass component is set aside while the low-pass image is subjected to subsequent division. This creates a kind of "3D" stack of image layers. Each layer is at a lower frequency and therefore fuzzier. This processing was pioneered by Philips Healthcare as UNIK (Unified Image Quality Enhancement), and by Agfa as MUSICA (Multi-Scale Image Contrast Amplification) with various innovations. The test image uses digital radiography images resulting from innovation from 14bit RAW digital conversion into JPG format. Image quality is calculated using Mean Square Error (MSE) and Peak Signal Noise Ratio (PSNR). The pyramidal decomposition application succeeded in improving the quality of digital radiography images with an average MSE reduction value of 0.018 and an average PSNR increase of 22.114 dB. Visually, there is a constant increase in contrast and detail, so it can be applied in the medical field.

✉ Alamat korespondensi:
E-mail: rudisetiawan@stikesannaher.ac.id

p-ISSN 2088-1509

INTRODUCTION

Current technological developments have brought major changes to the field of medical physics, especially radiodiagnostic technology. Conventional radiography which previously used film has been developed into radiography. One of them uses a digital camera as a detector (Susilo et al., 2014). This was done to catch up with existing radiograph results such as Computed Radiography (CR) which is expensive in terms of hardware and software (Susilo et al., 2013). For hardware, a CMOS sensor-based RD detector has been developed using a DSLR camera with more efficient and economical results (Fan et al., 2011). This is in line with the government's intention to reduce dependence on imported medical products and encourage the development of the domestic medical equipment industry (Law No. 18 of 2002). Meanwhile, software needs to be developed in image processing to improve image quality. The output results are in the form of an image processing system that can be applied to support existing radiography systems such as DR commercial product software systems. Digital radiographic images have become a crucial component in medical practice in this modern era (Susilo et al., 2011). Technological advances have brought significant changes in the acquisition and analysis of radiographic images, enabling more precise diagnosis and more effective digital treatment (Kurnianto et al, 2014). However, the success of diagnosis often depends on the quality of the images obtained. Quality issues such as noise, unclear details, and lack of accurate structural representation can hinder proper interpretation (Asif et al., 2023).

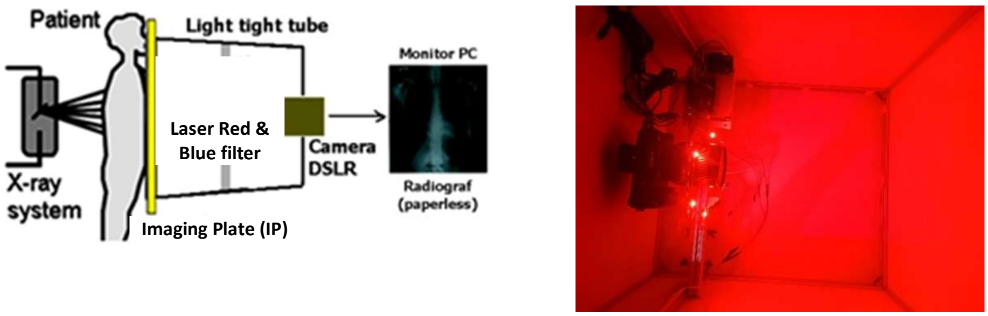
In an effort to improve the quality of digital radiographic images, image processing approaches have become an important subject in this research. One technique that has attracted attention is Pyramidal Decomposition, a method that has been proven effective in image processing in various contexts (Iswardani et al., 2018). The latest research uses the pyramidal method to improve image quality by (Asif et al, 2023) with an average increase in image contrast of 66.5%. Other research on improving image quality by (Wu et al., 2013), (Irrera et al., 2014) and (Sreelakshmi et al., 2015) which was previously applied obtained effective quality improvement results. The application of pyramid decomposition in multi-resolution image fusion on medical images carried out by (Kumari et al., 2014), (Hayat et al., 2019) and (Sharmal et al., 2020) is able to provide effectiveness in image processing. The pyramidal method is also able to support the preprocessing process in the Convolutional Neural Network process, this shows the effectiveness of the method in various image processing contexts. Pyramidal Decomposition is an approach that separates images into different levels of resolution, allowing image processing at different levels of detail. The use of this technique has been successful in reducing noise, increasing sharpness, and extracting important features from images in the field of computer image processing (Asif et al., 2023).

This research aims to explore the application of Pyramidal Decomposition, especially in improving the quality of digital radiographic images. By focusing on the use of this technique, the aim is to evaluate its effectiveness in reducing noise, sharpening details, and highlighting crucial features in digital radiography images, namely by calculating the Mean Square Error (MSE) and Peak Signal-to-Noise Ratio (PSNR) values. By improving the quality of digital radiographic images, it is hoped that this research will make a significant contribution to improving the accuracy of medical diagnoses and the development of more appropriate therapies.

METHOD

Radiograph Data Collection

The data capture system is built with a light tight tube behind the Imaging Plate. After being given laser light with a blue filter, the image of the object can be captured by the CMOS sensor from the DSLR camera to be displayed on the PC monitor screen (radiograph), so that film processing on the system conventional radiography is no longer necessary. Research data was taken from a digital radiography process resulting from innovation with 14bit RAW digital conversion into 8bit JPG format. The image is processed with a program according to the pyramidal decomposition processing process. After processing the image processing results, the MSE and PSNR values are calculated to determine the improvement. The image capture system is shown in Figure 1.



(a) (b)

Figure 1. (a). Flow diagram of a digital radiography imaging system modified from a conventional radiography system, (b). The process of taking images in a light-tight box

Image Processing with Pyramidal Decompositionr

Pyramidal decomposition has been developed by Philips Healthcare as Unified Image Quality Enhancement (UNIK), and by Agfa as Multi-Scale Image Contrast Amplification (MUSICA) with various innovations (Lanca et al., 2013; Asif et al., 2023). The results of this development have become commercial products that support software to improve the quality of digital radiography on the instruments they sell, such as CR and DR. The flow diagram of the pyramidal decomposition process is shown in Figure 2.

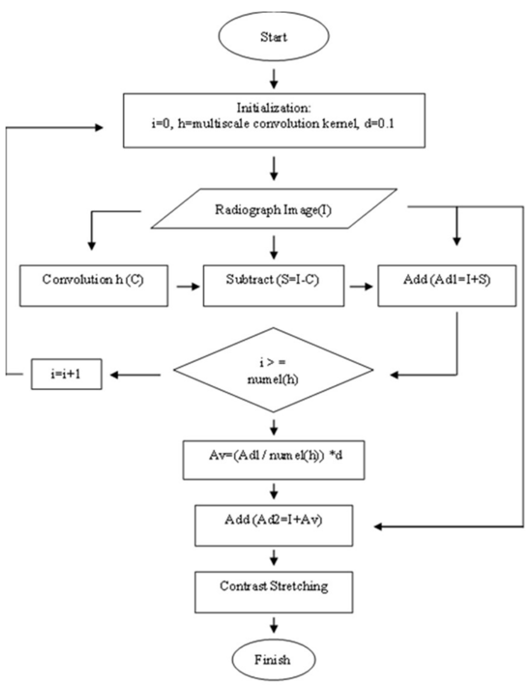


Figure 2. Flow diagram of the pyramidal decomposition process

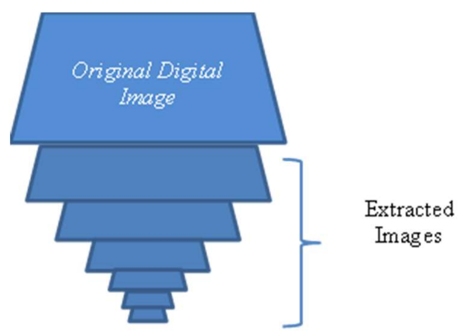


Figure 3. Multiscale processing with pyramidal decomposition

This digital image decomposition is called pyramidal decomposition. The original image is decomposed into several frequency bands, repeatedly divided into high-pass components and low-pass components. The high-pass component is set aside while the low-pass image is subjected to subsequent division. This creates a kind of "3D" stack of image layers as Figure 3 shows. Each layer is at a lower frequency and therefore fuzzier (Carroll, 2019).

The important thing in the decomposition process is the separation of high pass components from the reduction of low pass components (Ahmed H, Brettle D, 2011; Kaur, 2013). The low pass component is referred to as the blurred image. The low pass component is obtained from the convolution operation. The convolution of 2 functions f(x) and g(x) is defined in Equation (1) & Equation (2).

$$h(x) = f(x) * g(x) = \int_{-\infty}^{\infty} f(a)g(x-a)da \quad (1)$$

in this case, the sign * represents the convolution operator, and the variable a is an auxiliary variable (dummy variable). For discrete functions, convolution is defined as:

$$h(x) = f(x) * g(x) = \sum_{a=-\infty}^{\infty} f(a)g(xa) \quad (2)$$

In the convolution operation above, g(x) is called the convolution kernel or filter kernel. The kernel g(x) is a window that is operated in a shifted manner on the input signal f(x), in which case, the sum of the multiplication of the two functions at each point is the result of the convolution which is expressed as the output h(x).

For functions with two variables (two-dimensional or bidimensional functions) convolution is defined, the operation is show in Equation (3) and Equation (4).

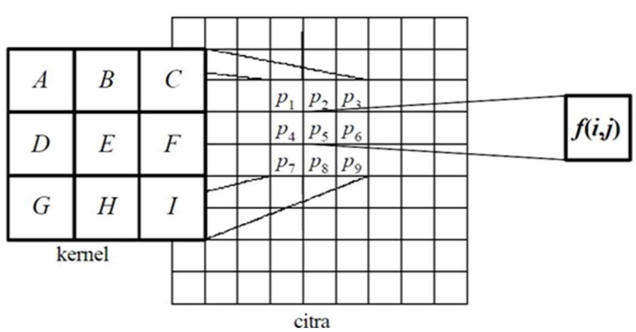
a) for constant functions

$$h(x,y) = f(x,y)*g(x,y) = \iint_{-\infty}^{\infty} f(a,b)g(x-a,y-b)dadb \quad (3)$$

b) for discrete functions

$$h(x,y) = f(x,y)*g(x,y) = \sum_{a=-\infty}^{\infty}\sum_{a=-\infty}^{\infty} f(a,b)g(x-a,y-b) \quad (4)$$

The filter function g(x,y) is also called convolution filter, convolution mask, convolution kernel, or template. In the discrete realm the convolution kernel is expressed in matrix form (generally 3 x 3, but there are also sizes 2 x 2 or 2 x 1 or 1 x 2). The size of this matrix is usually smaller than the size of the image. Each element of the matrix is called a convolution coefficient. An illustration of convolution is shown in Figure 4.



$f(i,j) = A\,p1 + B\,p2 + C\,p3 + D\,p4 + E\,p5 + F\,p6 + Gp7 + H\,p8 + I\,p9$

Figure 4. Illustration of convolution

As a note, if the convolution result produces a negative pixel value, then that value is set to 0, conversely if the convolution result produces a pixel value greater than the maximum gray value, then the value is set to the maximum gray value.

Problems arise if the pixels being convolved are border pixels, because some of the convolution coefficients cannot be positioned on the image pixels (a "hanging" effect), as in the example is shown in Figure 5:

4	4	3	5	4	?
6	6	5	5	2	?
5	6	6	6	2	?
6	7	5	5	3	
3	5	2	4	4	

Figure 5. Illustration of the hanging problem

This kind of "hanging" problem always occurs on the left, right, top and bottom edge pixels. The solution to this problem is

1. Edge pixels are ignored, not convolved. This solution is widely used in libraries of image processing functions. In this way, the value of the edge pixels remains the same as the original image.
2. Duplication of image elements, for example elements of the first column are copied to column M+1, and vice versa, then convolution can be carried out on the edge pixels.
3. Elements marked with "?" assumed to be 0 or another constant, so that convolution of edge pixels can be carried out.

The solution with the three approaches above assumes that the edge of the image is very small in width (only one pixel) relative to the size of the image, so that the edge pixels do not show visible effects show in Figure 6 (Munir, 2004).

4	4	3	5	4
6	4	0	8	2
5	0	2	6	2
6	6	0	2	3
3	5	2	4	4

Figure 6. Edge pixels (which are not shaded) are not convolved

TESTING WITH MSE AND PSNR

MSE or Mean Square Error is a method of measuring control and quality which is shown in Equation 5.

$$MSE=\frac{1}{MN}\sum_{y=1}^{M}\sum_{x=1}^{N}[I(x,y)-I'(x,y)]^2 \quad (5)$$

MSE = *Mean Square Error*
M = the length of the image in pixels
N = image width in pixels
I(x,y) = Initial Image
I'(x,y) = Processed Image Results

Peak Signal to Noise Ratio (PSNR) is a measurement method that is widely used for image compression and reconstruction systems as shown by Equation 6 (Sara et al., 2019).

$$PSNR=10log_{10}\frac{(Peak\ value^2)}{\sqrt{MSE}} \quad (6)$$

PSNR = *Peak Signal to Noise Ratio*
Peak value = The maximum bit value in the image is 8 bits, (2^8 -1= 255)
MSE = *Mean Square Error*

Prosedur untuk menghitung porositas permukaan dengan metode bayangan SEM ini dilakukan dengan menggunakan software *OriginPro*.

RESULTS AND DISCUSSION

The results of the pyramidal decomposition image before reconstruction are shown in Figure 7. The pyramidal image as in Figure 7 is used to reconstruct the initial image to increase contrast and detail. The initial image is converted into several sizes and several frequencies of the initial image.

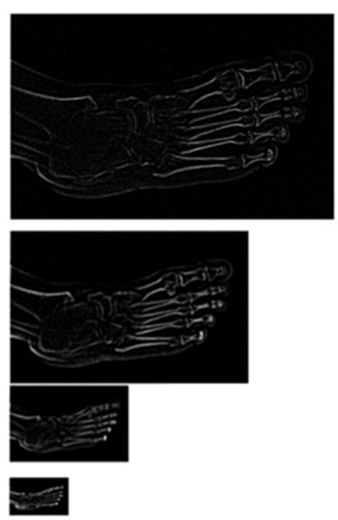
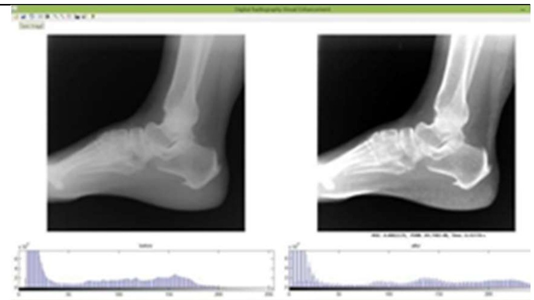
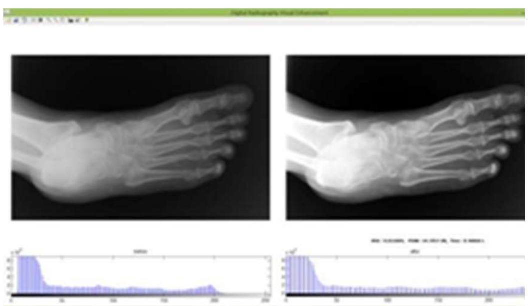
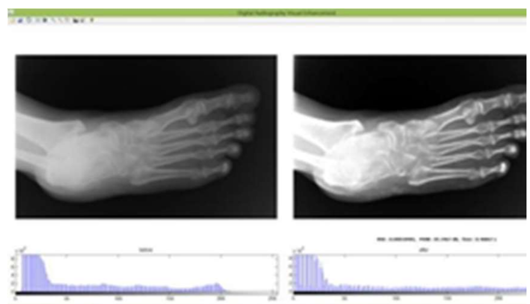
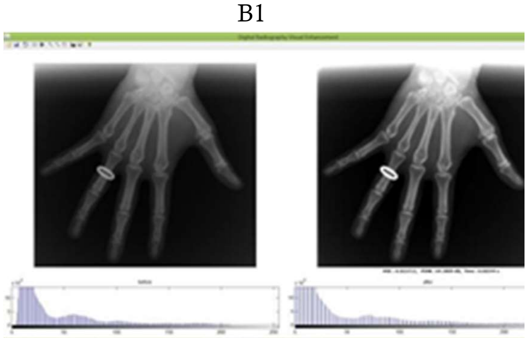
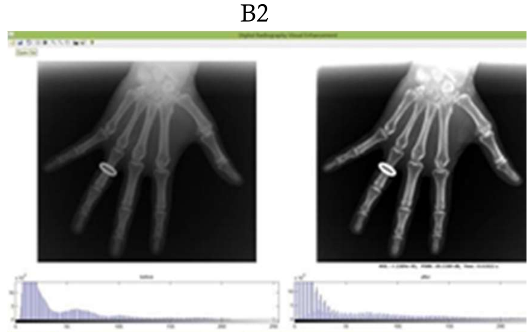
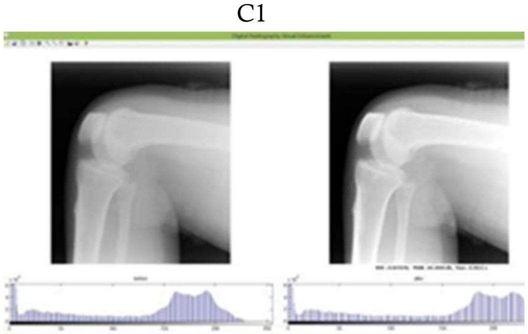
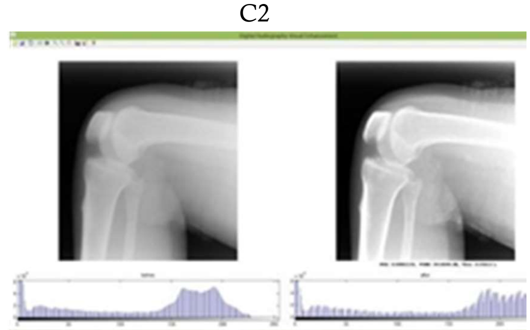
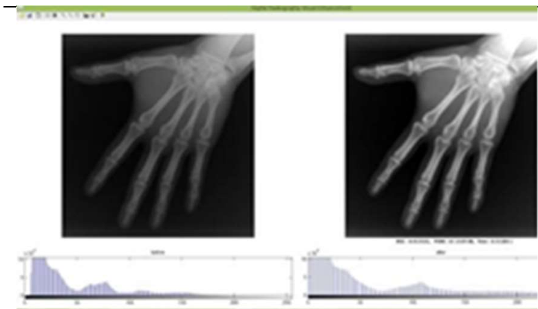
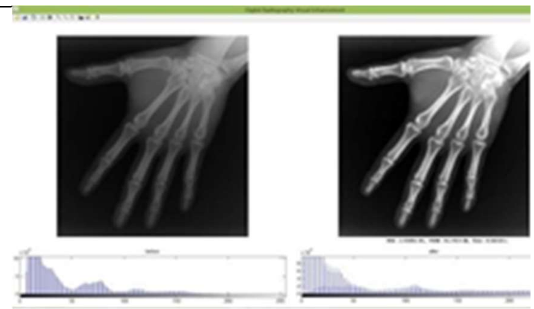


Figure 7. Pyramidal image results with changes in size and frequency before reconstruction

Processing is carried out in two processes, to obtain differences in MSE and PSNR values as an indication of improving image quality. The results of radiographic image processing data1 for process 1 and process 2 are shown in Table 1.

Table 1. Radiograph image processing results

1st Process Image Processing Results	2nd Process Image Processing Results
 A1	 A2
 B1	 B2
 C1	 C2
 D1	 D2

1st Process Image Processing Results	2nd Process Image Processing Results
	
E1	E2

The calculation results of MSE, PSNR and processing time from process 1 and process 2 of radiograph image processing are shown in the Table 2, Table 3 and Table 4.

Table 2. MSE calculation results

Data	MSE Process 1	MSE Process 2	MSE decline
1	0.022	0.0002	0.0238
2	0.024	0.0008	0.0238
3	0.023	0.0007	0.0223
4	0.015	0.0002	0.0148
5	0.012	0.0003	0.0117
Average	0.019	0.0004	0.018

Table 3. PSNR calculation results

Data	PSNR Process 1	PSNR Process 2	Improved PSNR
1	64.70 dB	85.34 dB	20.64 dB
2	64.21 dB	84.74 dB	20.53 dB
3	64.38 dB	89.53 dB	25.15 dB
4	66.20 dB	84.86 dB	18.66 dB
5	67.15 dB	92.74 dB	25.59 dB
Average	65.328 dB	87.442 dB	22.114 dB

Table 4 Duration of image processing process

Data	Process 1	Process 2
1	0.48 s	0.48 s
2	0.47 s	0.43 s
3	0.60 s	0.61 s
4	0.46 s	0.45 s
5	0.51 s	0.50 s

Tables 2 and Table 3 show the best decrease in MSE and increase in PSNR obtained in the 5th data with an MSE value of 0.0117, a PSNR value of 25.59 dB, processing time of 0.51 s and 0.50 s. Visually shows that the image after processing is able to provide even density changes in the bone so that there is detail and contrast in the 5th data as shown in Figure 8.

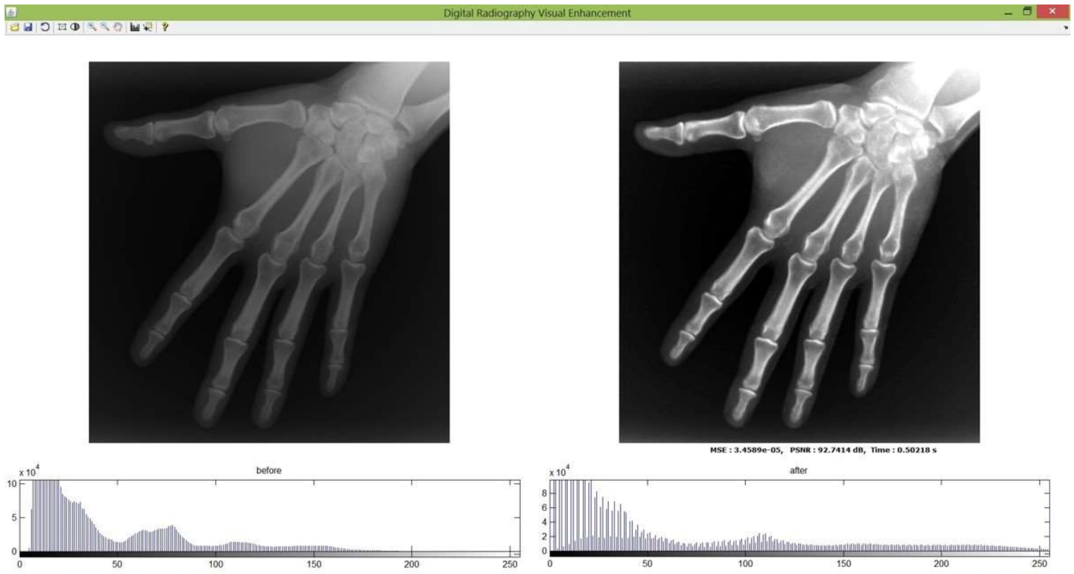


Figure 8. Interface display of image processing results for 5th data

Figure 8 shows the changes in contrast and detail in soft and hard tissue. This is in accordance with a decrease in the MSE value and an increase in the PSNR value. It can be seen in the histogram that the frequency range is evenly distributed throughout the dynamic range of the image, in the value range from 200 to 255 grayscale, it shows an increase in the number of frequencies, namely in the white part or represents the bone part, likewise in the range around the value 0 in the histogram shows an increase in the number of frequencies, which means color. black or represents the background becoming blacker so that the contrast increases visually. Changes in histogram values indicate changes in detail and contrast so that visually the image appears sharper. Low MSE values and high PSNR values indicate that the image processing technique has succeeded in improving image quality by approaching the original image. The calculation results show that the average MSE reduction value is 0.018 and the average PSNR increase is 22.114 dB. If calculated in percentage, the value of 22.114 dB is the same as an increase of 33.89%. This increase is quite significant, as a comparison to previous research (Asif et al, 2023) which only tested contrast values with the result of an increase in average contrast of 66.5% in that study, PSNR calculations as a basic control of image quality were not carried out.

The MSE and PSNR values appear constant with a range not far from the average value. This proves a stable increase in image quality in every processing and for all images. With these results, the development of software to improve the quality of medical images using pyramidal decomposition was successfully carried out, so that it can be applied to digital radiography as a result of the innovation in one package with hardware in the form of an X-ray detector based on a CMOS sensor DSLR camera.

CONCLUSION

The pyramidal decomposition application succeeded in improving the quality of digital radiography images with an average MSE reduction value of 0.018 and an average PSNR increase of 22.114 dB. Visually, there is a constant increase in contrast and detail in the bone, so it can be applied in the medical field, especially radiodiagnostics.

ACKNOWLEDGEMENTS

The author would like to thank the Ministry of Education and Culture for funding this research.

REFERENCE

Ahmed, H. S. S., & Nordin, M. J. (2011) improving diagnostic viewing of medical images using enhancement algorithms. *Journal of Computer Science*,7 (12): 1831-1838.

Asif, M. S., & Mahesh R. J. (2023). On the application of log compression and enhanced denoising in contrast enhancement of digital radiography images. *Arxiv*, 2304.04018v2.

Brettle, D. S., & Carmichael, F. (2011). The impact of digital image processing artefacts mimicking pathological features associated with restorations. *British Dental Journal*, 211, 167-170.

Carroll, Q. B. (2013). Radiography in the digital age: physics, exposure, radiation biology. *Radiology*, 267 (2).

Fan, H., Durko, H. L., Moore, S. K., Moore, J. W., Miller, B. W., Furenlid, L. R., Pradhan, S., & Barrett, H. H. (2010). DR with a DSLR: digital radiography with a digital single-lens reflex camera. *Proceedings of Spie--the International Society for Optical Engineering*, 1-12.

Hayat, N., & Imran, M. (2019). Multi-exposure image fusion technique using multi-resolution blending. *IET Image Process*, 13, 2554-2561.

Irrera, P., Bloch, I., & Delplanque, M. (2014). Contrast enhancement of micro dose x-ray images. *2014 IEEE 11th International Symposium on Biomedical Imaging*, 489-492.

Iswardani, A., & Hidayat, W. (2018). Mammographic image enhancement using digital image processing technique. *International Journal of Computer Science and Information Security*, 16(5).

Kurnianto, K., Putra, I. M., & Susila I. P. (2014). Perekayasaan perangkat radiografi digital untuk industri. *Prosiding Pertemuan Ilmiah Perekayasaan Perangkat Nuklir*, 261-274.

Kaur, G. (2013). An enhancement of classical unsharp mask filter for contrast and edge preservation. *International Journal of Engineering Sciences & Research Technology*, 2277-9655.

Kumari, S., Mahesh, M., & Srikant, L. (2014). Image fusion techniques based on pyramid decomposition. *International Journal of Artificial Intelligence and Mechatroni*, 2(4)

Lanca L., & Silva A. (2013). Digital imaging systems for plain radiography. *Springer Science Business Media New York*.

Munir, R. 2004, Pengolahan Citra Digital dengan Pendekatan Algoritmik, Informatika Bandung.

Sara, U., Morium, A., Mohammad, S. U. (2019). Image quality assessment through FSIM, SSIM, MSE and PSNR—a comparative study. *Journal of Computer and Communications*, 7(3), 8-18.

Sharma1, A. M., Ayush, D., Bhawna, G., Renu, V., & Sunil, A. (2020). From pyramids to state-of-the-art: a study and comprehensive comparison of visible–infrared image fusion techniques. *IET Image Process*, 14(9), 1671-1689.

Sreelakshmi, S., & Anoop, K. J. (2015). Image contrast enhancement using pyramidal transforms and svd. *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, 4(7).

Susilo, S., Budi W. S., Kusminarto, K. & Suparta, G.B. (2013). Kajian radiografi digital tulang tangan. *Jurnal Berkala Fisika*, 16(1), 15 – 20.

Susilo, S., Budi W. S., & Kusminarto, K. (2011). Analisis homogenitas bahan acrylic dengan teknik radiografi sinar-x, *Jurnal Fisika*, 1(1), 29-34.

Susilo, S., Supriyadi, S., Sunarno, S., Setiawan, R., & Wibowo, E. (2013). Kajian sistem radiografi digital sebagai pengganti sistem computed radiography yang mahal. *Jurnal Fisika Indonesia*. 17(50), 40-43

Susilo, S., Supriyadi, S., Sunarno, S., & Setiawan, R. (2014) rancang bangun sistem penangkap gambar radiograf digital berbasis kamera DSLR. *Jurnal Pendidikan Fisika Indonesia*, 1(1), Hal 66-74.

Wu, S., Yu, S., Yang, Y., & Xie, Y. (2013). Feature and contrast enhancement of mammographic image based on multiscale analysis and morphology. *Computational And Mathematical Methods In Medicin*e. 2013, 1-8.