Strojnícky časopis – *Journal of* MECHANICAL ENGINEERING,
VOL 73 (2023), NO 2, 1 – 8

CT-SCAN-BASED APPROACH FOR TURBINE BLADE GEOMETRY EXTRACTION

AL-AKAM Aws [1*], M. AL JUBOORI Ameen [2]

[1] *Faculty of Engineering/ Al-Mussayib, University of Babylon in Bratislava, Energy and Renewable Energy department, Al-Mussayib, 15001 Babil, Iraq, e – mail: aws.al-akam@uobabylon.edu.iq*
[2] *Al-Mustaqbal University, College of Engineering and Technology, Biomedical Engineering Department, Hillah, 15001 Babil, Iraq*

Abstract: This paper presents a method for the assessment of the geometrical properties of the turbine blade after a long running time. This method uses a medical imaging device (CT-Scan) to provide segmentation images of the turbine blade. Image processing technique was employed to produce the cross-sectional properties such as area, centroid, minimum moment of inertia, maximum moment of inertia, and the angle of twist of the principal axes along the blade span. This geometrical information was produced using MATLAB code and validated against Image-J software data. This method can be used as a nondestructive method to evaluate the geometry of the turbine.

KEYWORDS: Turbine blade, CT-Scan, image processing, geometry.

1 Introduction

Complex components are increasingly in use in modern engineering. Aero-engine industrial gas turbines and many other engineering applications have many complex components. Turbine blades, for example, have optimized curved surfaces and three-dimensional geometrical features. The turbine and compressor blade in a gas turbine are subjected to complex gas or air flow features. The impact of the flow with time is expressed by surface corrosion. This would affect the lifespan of the blade. Therefore, it is vital to assess the geometrical feature of the blade after a specific period. Having the geometrical characteristics of the turbine blade after a particular period will enable the assessment of the aerodynamic performance of the blade by employing computational fluid dynamics (CFD) techniques. Moreover, comparing the modern and previous designs of the turbine blade will indicate how the blade's performance might decrease with time.

Mitchell KW [1] first attempted to evaluate the wall thickness dimension using computed Tomography with moderate accuracy. In 2005, the first computed tomography for dimension measurement was invented [2]. Several developments were conducted to conduct a geometrical assessment of large components and increase the power to break through the material volume [3]. Computed Tomography was used in medical and industrial applications. Although both scanners work on the same physical principle, they differ in their functions. Spatial accuracy in industrial Tomography is higher than in medical devices. The accuracy depends on the doses of radiation. Therefore, industrial scanners have very high radiation to enable penetration through the materials [4]. While in medical scanners, the patient should be exposed to the lowest amount of radiation. Reducing the radiation will influence the accuracy of the medical scanners [5].

X-ray computational tomography (CT) is one of the few technologies capable of non-destructively measuring a component's external and internal features [6]. Industrial scanners consist of movable detectors perpendicular to the stationary X-Ray source. The test subject is

DOI: 10.2478/scjme-2023-0017, Print ISSN 0039-2472, On-line ISSN 2450-5471

placed on a portable bed, which can rotate full turns to enable multiple projections. The captured image can be used for quality assessment or CAD applications [7].

The extracted image using CT scan technique will be processed to produce the geometrical feature of the component. The quality of the captured image is important to increase the sensitivity to the small, corroded region over the blade surface. The researchers conducted several studies to inspect the turbine blade using computed Tomography. The spatial resolution of the image was the main concern of the researchers. L. D. Harris et al. [8] investigated the impact of x-ray beam width on spatial resolution. The turbine blade was placed between the x-ray source and the detector. J. F. Moore [9] used edge detection to improve the spatial resolution and to verify the turbine blade airfoil.

This paper's contribution is to produce a nondestructive method to assess the life of an old turbo machines blade [10] and thermal load parts [11, 12]. This assessment is based on capturing the turbine blade's geometrical features to be implemented in several simulation tools for further analysis by using medical computed Tomography.

2 Scope of the current work

The approach that has been implemented in this paper consists of using experimental, theoretical analysis, and image processing. First of all, a CT-scan was made for the blade geometry, at which several sections were captured. Afterward, the image processing for the captured image was made to extract the main geometrical feature of the blade. A theoretical analysis was made to calculate the centroid, moment of inertia, and rotation angle.

3 Methodology

3.1 Experimental Procedure

The turbine blade was inspected using a medical CT-Scan (GE Medical Systems\Discovery CT 750 HD). The test was made with the concave half of the blade facing the bed of the CT-Scan to reduce the beam hardening effect of the reflected x-ray beams. The device setting was KVP 120, slice thickness 1.25 mm, and tube current 120 mA. Forty DICOM images were obtained to illustrate the variation in the cross-sectional geometrical properties along the blade length.

3.2 Theoretical Analysis

The slice images obtained using the CT-Scan device described the variation in the geometrical properties. These images are 512 ×512 pixels and 16 bits of grey images. The images are processed by using Image-j software. The reflected X-ray beams from the surface will intersect, producing an imaginary sold volume. This volume will make the edge detection of the turbine blade very hard. Therefore, the turbine blade is placed on the CT-Scan bed with its convex side upward. The convex side will shatter the reflected X-ray beams away from the blade and prevent the formation of bright regions near the blade.

3.3 Image Processing

Binary images have foreground and background only. The intensity of the pixel values in the foreground is 1.0, and in the background, it is 0.0. This property can be used to identify the region of interest in the image by evaluating the intensity of the pixels [13].

The area of the cross-section can be found by counting the number of pixels with an intensity equal to 1.0. This number is multiplied by the area of each pixel in mm^2. The following equations will be used to evaluate the cross-sectional area of the turbine blade.

Converting factor (B) = image length (pixels) / image length (mm) (1)

Pixels area (a) = s^2 where s is the dimension of the pixel (2)

Cross-sectional area (A) = N × a where N is the number of pixels (3)

The centroid of the cross-sectional area was located by using the first moment of the area, as shown in the equation below:

$$\text{First moment of area (MX)} = \sum_1^N a * ((n-1) * B + \frac{S}{2}) \quad (4)$$

$$\text{First moment of area (MY)} = \sum_1^N a * ((m-1) * B + \frac{S}{2}) \quad (5)$$

Where m and n are the matrix dimensions.

$$X_o = {M_y}/{A} \quad (6)$$

$$Y_o = {M_x}/{A} \quad (7)$$

Where (X_o & Y_o) are the coordinates of the center of the area.

The area moment of inertia is evaluated by using the second moment of area and parallel axes theorem as shown in the equations below:

$$\text{Moments of inertia } (I_x) = \sum_1^N (\left(\frac{s^4}{12}\right) + a * (n-1) * B + \frac{S}{2}) \quad (8)$$

$$\text{Moments of inertia } (I_y) = \sum_1^N (\left(\frac{s^4}{12}\right) + a * (m-1) * B + \frac{S}{2}) \quad (9)$$

$$\text{Product of inertia } (I_{XY}) = \sum_1^N a * ((m-1) * B + \frac{S}{2}) * ((n-1) * B + \frac{S}{2}) \quad (10)$$

$$\text{Moment of inertia } (I_{Xo}) = I_x - a * Y_o^2 \quad (11)$$

$$\text{Moment of inertia } (I_{Yo}) = I_y - a * X_o^2 \quad (12)$$

$$\text{Product of inertia } (I_{XoYo}) = I_{XY} - a * X_o * Y_o \quad (13)$$

Where $\boldsymbol{I_{Xo}}$, $\boldsymbol{I_{Yo}}$, $\boldsymbol{I_{XoYo}}$ are the moment and product of inertia of the cross-sectional area about the centroid coordinate system.

From these equations, the maximum and minimum moment of inertia can be found, and those values will identify the principal axe of deformations for the turbine blade.

$$I_{max\ \&\ min} = (\frac{I_{Xo} + I_{Yo})}{2} \pm \sqrt{\frac{(I_{Xo} - I_{Yo})^2}{4} + (I_{XoYo})^2} \quad (14)$$

The cross-sectional area varying along the turbine blade will cause the principal axes to rotate. The principal axes angle of rotation can be found from the equation below:

$$\text{Angle of rotation } (\alpha) = \frac{1}{2} * tan^{-1}\left(\frac{2 * I_{XoYo}}{I_{Yo} - I_{Xo}}\right) \quad (15)$$

4 Results and discussions

4.1 CT-Scan Outputs

The slice images will have a lot of bright regions that interfere with the body of the blade (Figure 1-a). Those bright regions will complicate the edge detection of the turbine blade. To remove these regions, the image is converted to 8-bit binary images. The image's brightness was reduced to facilitate the edge detection of the turbine blade (Figure 1-b). The turbine blade cross-section details are identified by using the thresholding technique (Figure 1-c). This procedure is repeated for every DICOM image to prepare them for image processing using MATLAB software.

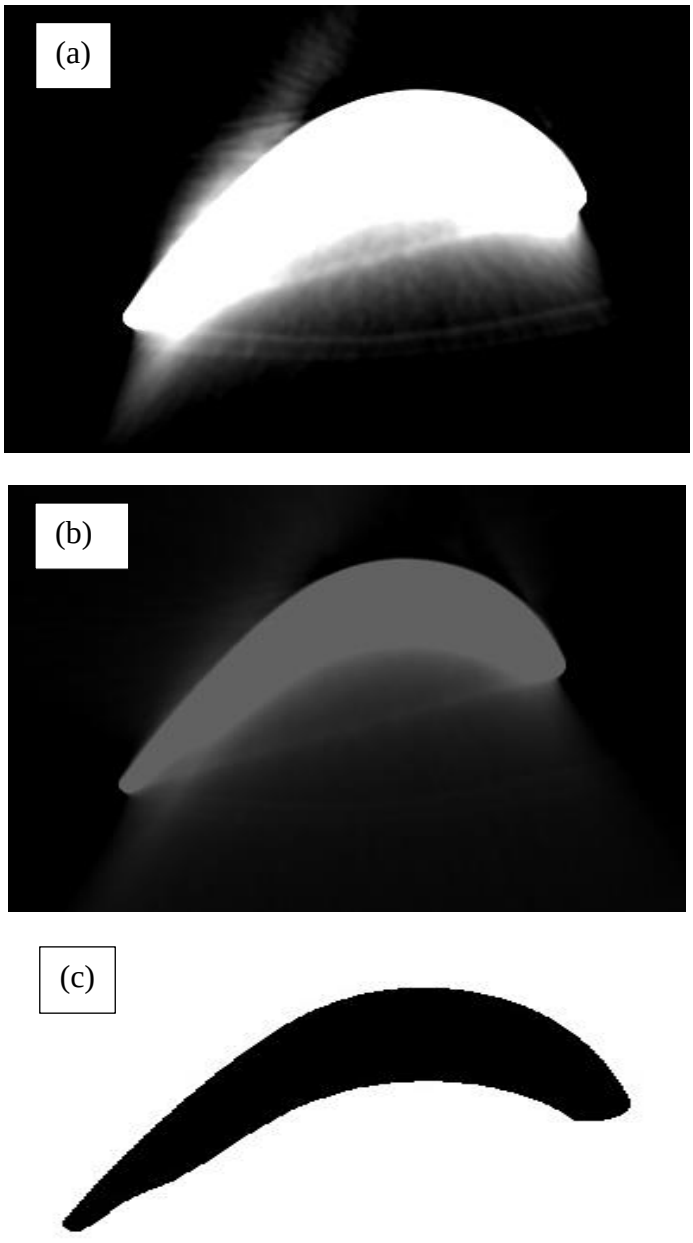


Fig. 1 DICOM image processing. (a) Original image, (b) image after reducing its brightness, (c) image after thresholding.

4.2 Captured geometrical characteristics of the blade

The geometrical factors of the cross-sectional area were evaluated by using MATLAB software. The variation of those properties along the blade span was investigated. Several images based on spanwise slices have been extracted. The slices start from the tip of the blade to the root. The cross-sectional area variation along the blade length is illustrated in Figure 2. The area increases almost linearly with the length of the blade and reaches its maximum value at the base of the blade.

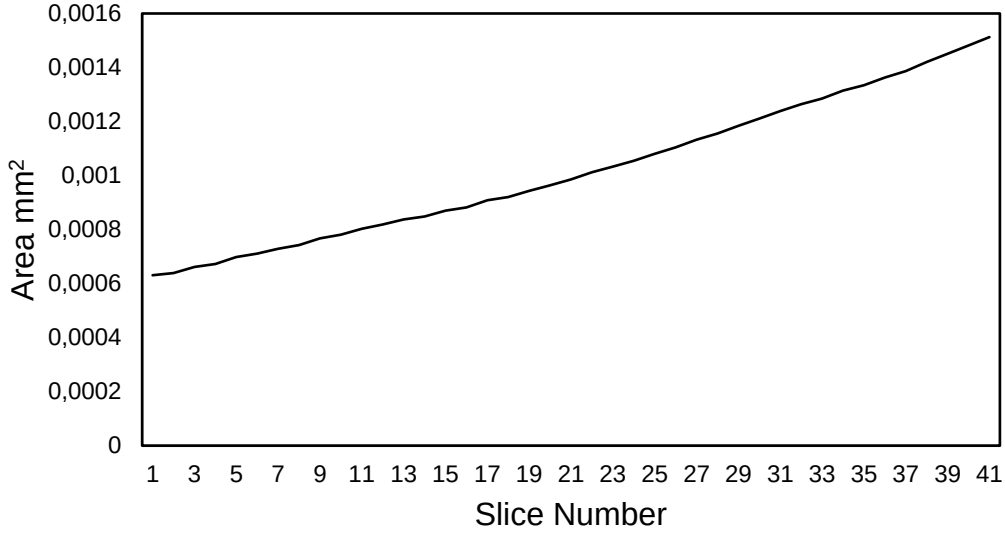


Fig. 2 The variation of the area along the blade span.

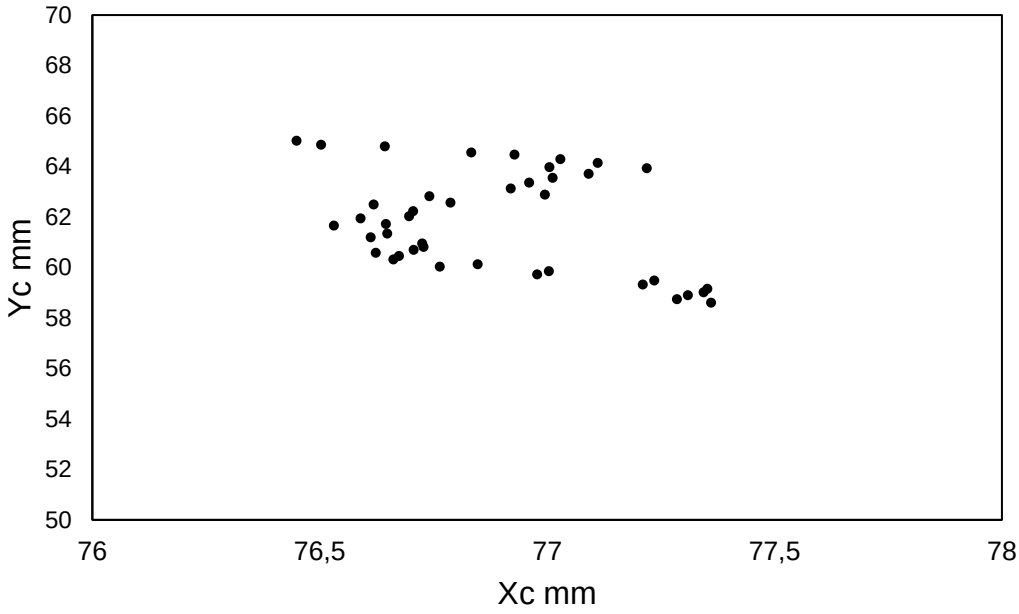


Fig. 3 Centroid trajectory of the centroid along the blade span.

The change in the cross-sectional area will influence the location of the centroid. Figure 3 shows the trajectory of the centroid along the blade span. The fluctuation in the location of the centroid does not exceed 1 mm between the farthest locations. This fluctuation can be related to the error due to the image processing in binary image preparation. The shape of the turbine blade is not symmetrical. Therefore, there will be two principal axes of deformations. These two axes are

very important to evaluate the mode shape of deformation during working conditions. The area moment of inertia is a very important geometrical property needed for many engineering calculations. Due to the dissimilarity in the cross-sectional, there will be two principal axes, maximum and minimum. Those axes are classified according to the value of the second moment of area. The variation of the maximum and minimum moment of inertia along the blade span is shown in Figure 4. The variation is almost linear for both. This linear increase can be attributed to the linear increase in the cross-sectional area and the relatively fixed location of the centroid.

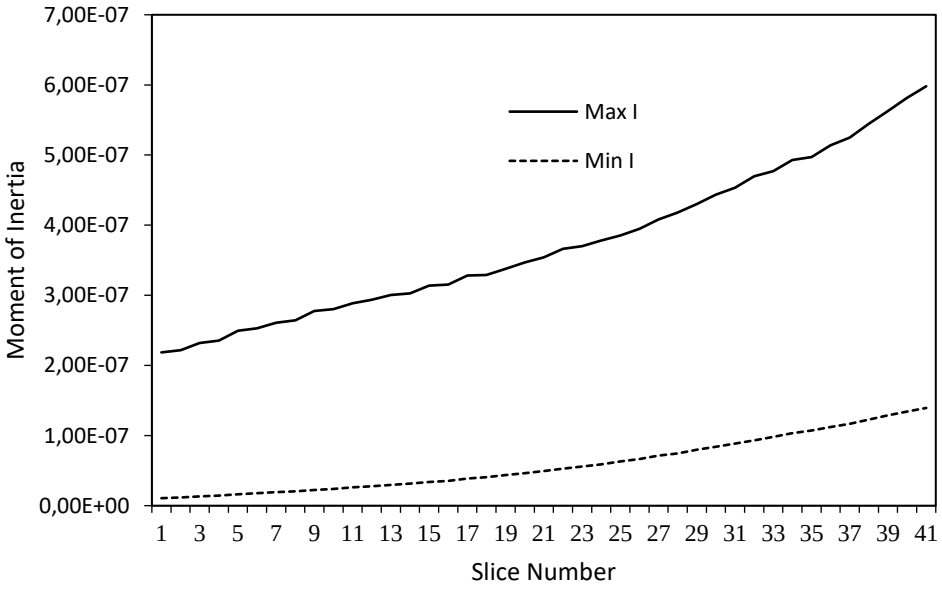


Fig. 4 Variation of the max and min moment of inertia along the blade span.

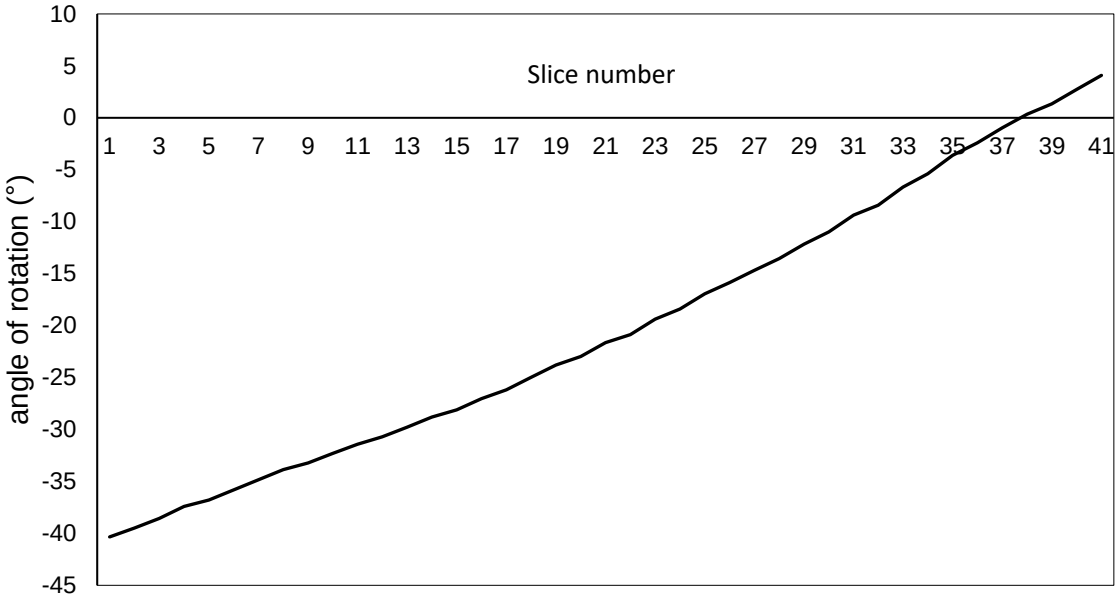


Fig. 5 Variation of the angle of rotation (α) of the principal axes along the blade span.

As stated above, there are two principal axes of deformation due to the change in the shape and value of the cross-sectional area. These principal axes are not stationary and will rotate due to the shape change of the cross-sectional area. The variation of the angle between those principal

axes along the blade length is plotted in Figure 5. The angle varies from -40 degrees at the top of the blade to 5º at the base of the blade. The increases are also linear due to the linear increases of the maximum and minimum moments of inertia.

CONCLUSION

The complex geometry of the turbine evaluates its geometrical properties, a difficult task. Image processing is a powerful tool that can be used as a nondestructive test to figure out the condition of the turbine blade after a long working time. This study presents a method to determine the geometrical techniques using a medical imaging device (CT-Scan). Industrial imaging devices are very expensive and rarely available. This method can be improved to evaluate other geometrical properties such as cord length and inlet and outlet angles. The obtained data can be used in reverse engineering or various engineering analyses such as vibration and stress analysis.

REFERENCES

[1] Mitchell, KW. "A Generalized Approach to Wall Thickness Measurements in CT Images", Topical Proc. Industrial Computerized Tomography, ASNT, pp. 120 – 124, **1989**. ISBN 0-931403-89-8.

[2] Hanke, R., Fuchs, T., Uhlmann, N. "X-ray Based Methods for Nondestructive Testing and Material Characterization", Nuclear Instruments and Methods in Physics Research A 591, pp. 14 – 18, **2008**.

[3] Rack, A., et al. "High Resolution Synchrotron-Based Radiography and Tomography Using Hard X-rays at the BAM Line (BESSY II)", Nuclear Instruments & Methods in Physics Research A 586, pp. 327 – 344, **2008**.

[4] Bartscher, M., Neuschaefer-Rube, U., Staude, A., Ehrig, K., Goebbels, J. "Application of an industrial CT reference standard for cast free-form shaped work pieces", Proc. Int. Symp. on Digital Ind. Radiology and CT, CD-ROM, paperWe.4.3, Berlin, Juni 20–22, **2011**.

[5] Bartscher, M., Hilpert, U., Goebbels, J., Weidemann, G. "Enhancement and Proof of Accuracy of Industrial Computed Tomography (CT) Measurements", CIRP Annals 56, pp. 495 – 498, **2007**.

[6] Bartscher, M., Neuschaefer-Rube, U., Staude, A., Ehrig, K., Goebbels, J. "Application of an industrial CT reference standard for cast free-form shaped work pieces", Proc. Int. Symp. on Digital Ind. Radiology and CT, CD-ROM, paper We.4.3, Berlin, Juni 20–22, **2011**.

[7] Bartscher, M., et al. "Achieving Traceability of Industrial Computed Tomography. Proc. 9th Int. Symp. on Measurement and Intelligent Instruments— ISMTII 2009", D.S. Rozhdestvensky Optical Society 1, pp. 256 – 261, **2009**.

[8] Lowell, D. Harris et al. "Optimizing Spatial resolution with the mechanical design of an X-ray Computed tomography scanner", Review of progress in Quantitative Nondestructive evaluation 9, (Ed. D.O. Thompson and D.E. Chimenti), Plenum Press, New York, pp. 423 – 430, **1990**.

[9] Moore, John F. "Evolution of Computed Tomography", Materials Evaluation 48, pp. 630 – 640, **1990**.

[10] Vishwakarma, N., Renuke, A., Phalle, V.M. "Effect of Tapered Interference Fit between Impeller and Shaft in Turbo Machines", Strojnícky časopis – Journal of Mechanical Engineering 68 (3), pp. 25 – 32, **2018**. DOI: 10.2478/scjme-2018-0024

[11] Chríbik, A., Polóni, M., Lach, J., Jančošek, Ľ., Kunc, P., Zbranek, J. "Internal Combustion Engine Powered by Synthesis Gas from Pyrolysed Plastics", Strojnícky časopis – Journal of Mechanical Engineering 66 (1), pp. 37 – 46, **2016**. DOI: 10.1515/scjme-2016-0009

[12] Kutiš, V., Jakubec, J., Paulech, J., Gálik, G., Sedlár, T. “CFD Analysis of Downcomer of Nuclear Reactor VVER 440”, Strojnícky časopis – Journal of Mechanical Engineering 66 (2), pp. 55 – 62, **2016**. DOI: 10.1515/scjme-2016-0018

[13] Gonzalez, R. C., Woods, R. E. “Digital Image Processing”, PrenticeHall, 3rd ed., **2007**.