Jakub PĘKSIŃSKI[1], Grzegorz MIKOŁAJCZAK[1], Janusz Paweł KOWALSKI[2]

Zachodniopomorski Uniwersytet Technologiczny, Wydział Elektryczny (1), Pomorski Uniwersytet Medyczny (2)

Algorithm for creating panoramic images based on Mean Square Error

Streszczenie. *W artykule autorzy przedstawili metodę dopasowania cyfrowych obrazów pozyskanych za pomocą aparatu cyfrowego. Metoda dopasowania opiera swoją zasadę działania na analizie porównawczej dwóch obrazów za pomocą popularnej miary jakości oceny obrazów cyfrowych jaką jest błąd średniokwadratowy. Zastosowany algorytm dopasowania obejmuje synchronizację obrazów zarówno w płaszczyźnie X i Y oraz dopasowanie związane z kątem obrotu między obrazami. Zaproponowany algorytm dopasowania można zastosować do wykonywania zdjęć panoramicznych. (**Algorytm do tworzenia zdjęć panoramicznych wykorzystujący błąd średniokwadratowy**).*

Abstract. *In this paper the authors present a method of matching digital images recorded with a digital camera. The functioning principle of the proposed method is based on the comparison analysis of two images using a popular measure of digital image quality assessment, i.e. mean square error. The applied algorithm includes synchronization of images both in the X and Y planes as well as adjustment related to the angle of rotation between the images. The proposed matching algorithm can be used to create panoramic images.*

Słowa kluczowe: dopasowanie obrazów, błąd średniokwadratowy, obrazy panoramiczne, przygotowanie danych.
Keywords: synchronization of images, mean square error, panoramic image, data match.

doi:10.12915/pe.2014.03.55

Introduction

Dynamic development of digital image processing in the recent years has resulted in the decline of analogue photography. Currently, we are surrounded by devices designed for digital acquisition and processing of images [6]. Obviously, such devices are characterized by different technical specifications, having considerable influence on the quality of the image, as well as on the type of functions that the device itself offers for automatic processing, correction and adjustment of a digital image. Basic functions offered by digital cameras are related to image correction.

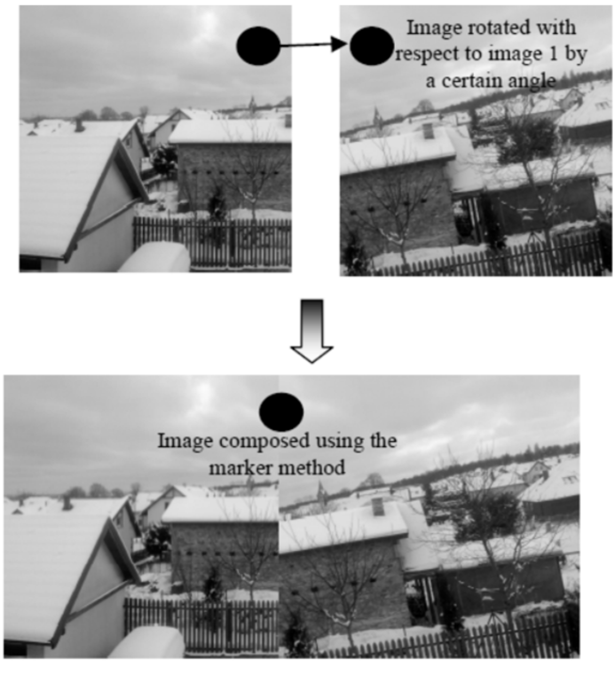

Fig.1. Example of panoramic image creation using the marker method when deformation in the case of rotating images against each other

The better the device is, the more functions it offers, e.g. so-called panoramic images. The basic rule for an algorithm applied in compact cameras is based on marking control points on the images and then matching these points together. This process is very simple and in most cases it is impossible to create a panoramic image of satisfactory quality, precisely reflecting the reality from particular shots. Such situation occurs when particular partial images used to create a panoramic image are rotated against each other by a certain angle, as exemplified in Fig. 1.

It is clearly visible that the image composed using the marker method is deformed and does not satisfactorily reflect the reality.

The algorithm for creating panoramic images

The algorithm functions on the basis of analysing two images using a popular measure of quality assessment called Mean Square Error (MSE) [1,5]:

$$MSE = \frac{\sum_{x=1}^{M}\sum_{y=1}^{N}[(f_{in}(x,y) - f_{out}^{'}(x,y)]^2}{M \cdot N} \quad (1)$$

where: $f_{in}(x,y)$ - original image; $f_{out}(x,y)$ - conversed image.

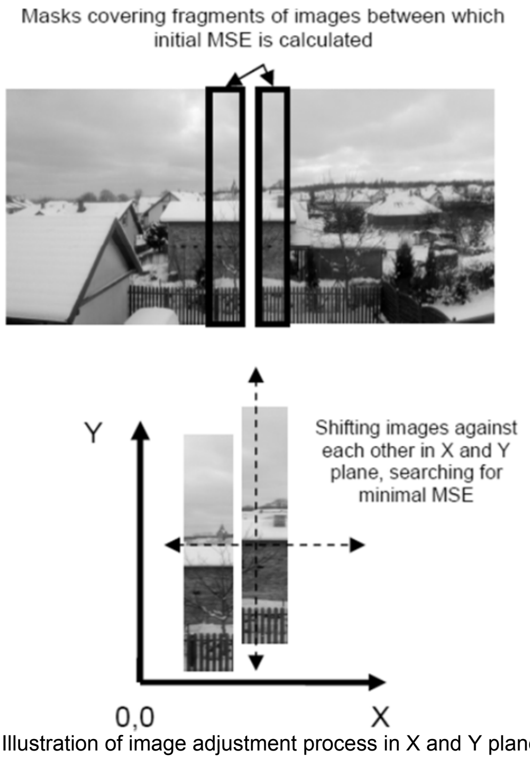

Fig.2. Illustration of image adjustment process in X and Y plane

The feature of the quality assessment measure described with formula 1 is that its indication is strongly dependent on the shift between the assessed images [2, 3, 4]. This feature of the quality assessment measure has been used to create the algorithm for panoramic images.

The algorithm proposed by the authors may be used both to create panoramic images when only the synchronization in X and Y plane is required, but also when the images are slightly shifted against each other and rotated by a certain unknown angle of rotation. In such case, the image synchronization requires taking into account the rotation between the images.

Image synchronization in X and Y plane is based on the following steps (Fig.2. illustrates the whole process):

• Choosing two masks of the same size covering the marginal fragments of the images we want to adjust to each other;

• Examining the initial error between them, in accordance with formula 1;

• Shifting fragments of the images by 1 pixel in X and Y plane, in order to determine the smallest value of MSE;

Synchronization of images rotated with respect to each other by a certain angle is a more complex process, where we need to identify:

• Axis of rotation;

• Angle of rotation between images.

In order to determine the axis of rotation, both images should be divided into segments of the same size.

Each of the image fragments 1-1a, 2-2b, is compared using MSE. The axis of rotation between the images will be identified where MSE has the minimum value (Fig.3)

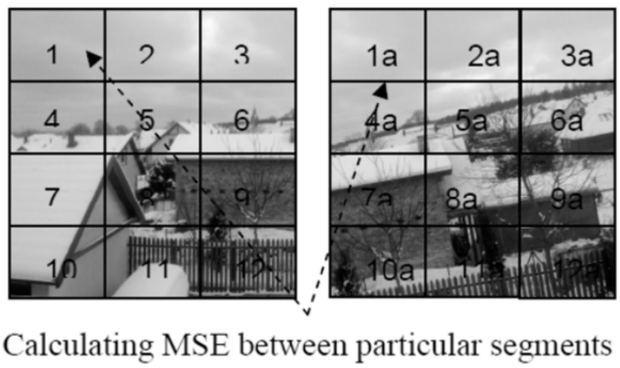

Fig.3. Determining MSE between image segments in order to find the minimum

After identifying the image segment indicating the minimum MSE value, it is necessary to establish the accurate position value of the axis of rotation between images. In order to do so, image fragments with the minimum value must be determined. The axis of rotation will be located exactly where MSE has the minimum value.

After determining the axis of rotation between images, the next step is to identify the angle of rotation of the images against each other. Therefore, the outmost edge is selected from the determined centre of rotation between images (O). Thus, a segment of (a) length is obtained, beginning in the axis of rotation and ending in point (X). After determining the segment and calculating its length, we select a mask of 20x20 pixel dimension (the size has been determined experimentally by the authors of this paper). Shifting the mask 20x20 along the outmost edge from the centre of rotation, the minimum MSE value between images is sought. Where MSE reaches its minimum value, point (Y) is determined, due to which section (b) is obtained, beginning in point (X) and ending in point (Y). The process has been presented in Fig.4.

Once the axis of rotation and two segments of a and b length are determined, the next step is to determine the value of the angle of rotation between images. Therefore we apply the trigonometric dependence on the value of the tangent of the angle of a right-angled triangle described:

$$\alpha = arctg(\tfrac{b}{a}) \quad (2)$$

where: α - angle of rotation sought; a, b – length of segments.

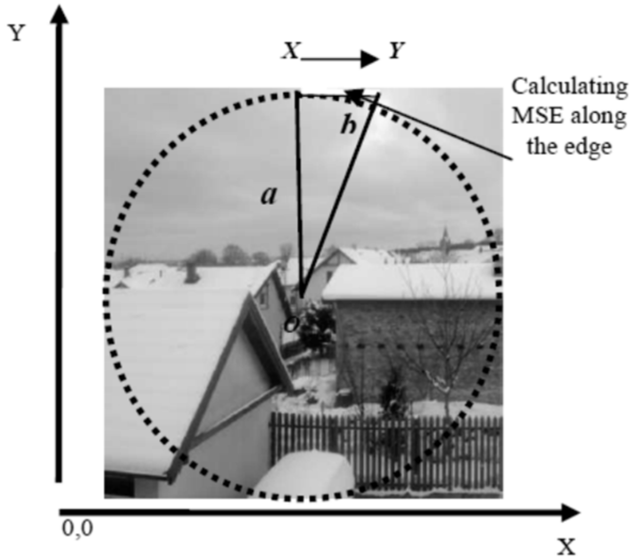

Fig.4. Determining the angle of rotation between images

The next step of the algorithm is adjusting two images rotated with respect to each other in order to create a panoramic image. This is achieved by means of transformation described with formula 3 for image rotation against arbitrary axis and arbitrary angle α [7, 8].

$$\begin{aligned} x_n &= A + (x_1 - A)\cdot\cos(\alpha) - (y_1 - B)\cdot\sin(\alpha) \\ y_n &= B + (x_1 - A)\cdot\sin(\alpha) + (y_1 - B)\cdot\cos(\alpha) \end{aligned} \quad (3)$$

where: x_n, y_n - value of the position of a new pixel after rotation; x_1 y_1, - value before rotation

The process of image rotation against an arbitrary axis and an arbitrary angle has been shown in Fig.5.

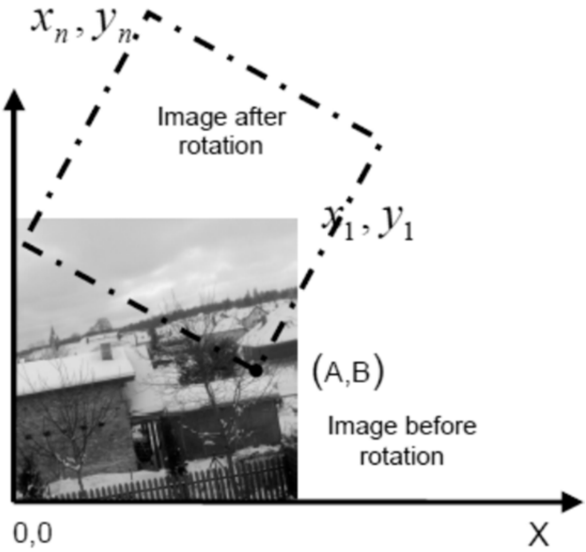

Fig.5. Image rotation by an arbitrary angle

Results of experimental studies

Tables 1 – 4 below show results of experimental studies for images shifted against each other in X and Y plane. Tables 5 - 8 show results of experimental studies for images shifted against each other by a certain angle.

Table 1. The experimental results for SVGA images. Adjustments in X and Y plane, image dimensions 800x600 pixels, SVGA standard (4:3)

SVGA images	Preset shifting		Determined shifting		Calculation time [s]
	X	Y	X	Y	
Image 1	-1	-1	-1	-1	0.067
Image 2	-1	-2	-1	-2	0.064
Image 3	-1	-3	-1	-3	0.072
Image 4	1	1	1	1	0.066
Image 5	1	2	1	2	0.069
Image 6	1	3	1	3	0.076
Image 7	-3	3	-3	3	0.091
Image 8	-4	4	-4	4	0.097
Image 9	11	-3	11	-3	0.109
Image 10	-11	6	11	6	0.154

Table 2. The experimental results for XGA images. Adjustments in X and Y plane, image dimensions 1024x768 pixels, XGA standard (4:3)

XGA images	Preset shifting		Determined shifting		Calculation time [s]
	X	Y	X	Y	
Image 1	-1	-1	-1	-1	0.077
Image 2	-1	-2	-1	-2	0.074
Image 3	-1	-3	-1	-3	0.082
Image 4	1	1	1	1	0.076
Image 5	1	2	1	2	0.079
Image 6	1	3	1	3	0.809
Image 7	-3	3	-3	3	0.111
Image 8	-4	4	-4	4	0.137
Image 9	11	-3	11	-3	0.204
Image 10	-11	6	11	6	0.259

Table 3. The experimental results for WSVGA images, Adjustments in X and Y plane, image dimensions 1024x600 pixels, WSVGA standard (16:9)

WSVGA images	Preset shifting		Determined shifting		Calculation time [s]
	X	Y	X	Y	
Image 1	-1	-1	-1	-1	0.063
Image 2	-1	-2	-1	-2	0.068
Image 3	-1	-3	-1	-3	0.062
Image 4	1	1	1	1	0.069
Image 5	1	2	1	2	0.061
Image 6	1	3	1	3	0.729
Image 7	-3	3	-3	3	0.061
Image 8	-4	4	-4	4	0.067
Image 9	11	-3	11	-3	0.054
Image 10	-11	6	11	6	0.069

In order to standardize the research results, the same image saved in different resolutions and proportions has been shifted and rotated. All the shifting and rotation were forced artificially.

A PC with Intel Core 2 duo processor and Matlab environment were used for the purpose of this research. Adjustment considering rotation between images.

Analysis of the results of experimental studies presented in tables 1 to 8 proves the effectiveness of the adjusting algorithm.

Table 4. Results of experimental studies for HD images, adjustments in X and Y plane, image dimensions 1920x1080 pixels, HD standard (16:9)

HD images	Preset shifting		Determined shifting		Calculation time [s]
	X	Y	X	Y	
Images 1	-1	-1	-1	-1	0.211
Images 2	-1	-2	-1	-2	0.286
Images 3	-1	-3	-1	-3	0.297
Images 4	1	1	1	1	0.244
Images 5	1	2	1	2	0.269
Images 6	1	3	1	3	0.298
Images 7	-3	3	-3	3	0.309
Images 8	-4	4	-4	4	0.398
Images 9	11	-3	11	-3	0.401
Images10	-11	6	11	6	0.429

Table 5. The experimental results for rotation between SVGA images

SVGA images	Preset axis of rotation		Preset angle [°]	Determined axis of rotation		Determined angle of rotation [°]
	X	Y		X	Y	
Image 1	400	300	1	400	300	1
Image 2	400	300	2	400	300	2
Image 3	400	300	3	400	300	3
Image 4	300	400	1	300	400	1
Image 5	300	400	2	300	400	2
Image 6	300	400	3	300	400	3
Image 7	350	250	1	350	250	1
Image 8	150	150	3	150	150	3
Image 9	200	200	2	200	200	2
Image10	350	180	1	350	180	1

Table 6. The experimental results for rotation between XGA images

XGA images	Preset axis of rotation		Preset angle [°]	Determined axis of rotation		Determined angle of rotation [°]
	X	Y		X	Y	
Image 1	512	384	1	512	384	1
Image 2	512	384	2	512	384	2
Image 3	512	384	3	512	384	3
Image 4	384	512	1	384	512	1
Image 5	384	512	2	384	512	2
Image 6	384	512	3	384	512	3
Image 7	400	300	1	400	300	1
Image 8	300	400	1	300	400	1
Image 9	250	300	2	250	300	2
Image10	200	200	1	200	200	1

Table 7. The experimental results for rotation between WSVGA images

WSVGA images	Preset axis of rotation		Preset angle [°]	Determined axis of rotation		Determined angle of rotation [°]
	X	Y		X	Y	
Image 1	512	300	1	512	300	1
Image 2	512	300	2	512	300	2
Image 3	512	300	3	512	300	3
Image 4	300	512	1	300	512	1
Image 5	300	512	2	300	512	2
Image 6	300	512	3	300	512	3
Image 7	450	300	1	450	300	1
Image 8	320	400	1	320	400	1
Image 9	380	300	2	380	300	2
Image10	250	300	1	250	300	1

In order to prove the effectiveness of image adjustment, an experimental study has been conducted, based on comparing the images before adjustment with the images where the adjusting algorithm proposed by the authors has been applied. The comparison has been made using the MSE measure. The results have been presented in tables 9 and 10.

Table 8. The experimental results for rotation between HD images

HD images	Preset axis of rotation		Preset angle [°]	Determined axis of rotation		Determined angle of rotation [°]
	X	Y		X	Y	
Image1	960	540	1	960	540	1
Image2	960	540	2	960	540	2
Image3	960	540	3	960	540	3
Image4	540	960	1	540	960	1
Image5	540	960	2	540	960	2
Image6	540	960	3	540	960	3
Image7	500	400	1	500	400	1
Image8	400	300	1	400	300	1
Image9	500	600	2	500	600	2
Image10	350	600	1	350	600	1

The analysis of the results of experimental studies presented in tables 9 and 10 leads to the conclusion that adjustment of the images shifted against each other in X and Y plane is perfect. The adjustment of images rotated against each other is burdened with error despite determining the axis and the angle of rotation. The error is due to the fact that rotating digital images is a complex process requiring interpolation [7,9], which introduces distortion that influences the indication of the MSE quality measure.

Table 9. The results of comparison of images shifted against each other in X and Y plane

HD Images	MSE before adjustment	MSE after adjustment
Image 1	365.924	0.000
Image 2	278.678	0.000
Image 3	439.023	0.000
Image 4	211.431	0.000
Image 5	191.278	0.000

Table 10. Results of comparing images shifted against each other by a certain angle

HD Images	MSE before adjustment	MSE after adjustment
Image 1	478.345	38.278
Image 2	511.878	69.311
Image 3	321.123	28.190
Image 4	638.134	86.497
Image 5	291.728	18.078
Image 5	156.756	26.189

Table 11. The results of comparison methods for creating panoramic images

Images	MSE method after placing an image tag	MSE authors in the method
Image 1	378.109	68.106
Image 2	401.298	111.876
Image 3	679.071	143.200
Image 4	200.100	43.345
Image 5	156.756	26.189

Comparison of test results

In order to verify the effectiveness of the method has been compared with the method based on the markers [10]. Artificially divided panoramic image and then were submitted it using both methods and compared with the original before splitting. The results of the comparative study are shown in table 11

Final conclusions

The authors of this paper propose an effective algorithm for adjusting images shifted against each other in X and Y plane and rotated by a certain angle. The proposed algorithm makes it possible to determine the exact value of shifting between images and accurate determination of the axis and the angle of rotation between rotated images.

The proposed algorithm may be used to create panoramic images as well as in many fields of digital signal processing.

REFERENCES

[1] Kornatowski J., Kryteria obiektywnej oceny obrazów cyfrowych, *XXVIII IC-SPETO. T. 2 Gliwice*, (2005), nr.5, 427-430

[2] Pęksiński J., Mikołajczak G., Correction of the digital image shift in two - dimensional plane, *Journal of Electrical Engineering*, 60 (2009), n. 6, 341-351

[3] Pęksiński J., Mikołajczak G., The preparation of input data in digital image processing, *Przegląd Elektrotechniczny,* 89 (2013), no 3, 282-284

[4] Kornatowski E., Probabilistyczna miara wierności odwzorowania sygnału, *Kwartalnik Elektroniki i Telekomunikacji*, 45 (1999), nr 3-4, 297-309

[5] Pęksiński J., Mikołajczak G., Differential approximation of the 2-D Laplace operator for edge detection in digital images, *Lecture Notes in Artificial Intelligence*, 6423 (ICCCI`2010 Part III), Springer Verlag, 2010, 194-199

[6] Podpora M., Computer vision in parallel computing , *Przegląd Elektrotechniczny,* 83 (2007), no 11, 68-70

[7] Kornatowski E., Pęksiński J., Kowalski J., Mikołajczk G., *Inżynieria cyfrowego przetwarzania obrazów: Filtracja liniowa i nieliniowa obrazów dyskretnych*, Hogben (2005)

[8] Pęksiński J., Mikołajczak G., The Synchronization of the Images Based on Normalized Mean Square Error Algorithm, *Advances in Intelligent and Soft Computing* vol. 80 - Advances in Multimedia and Network Information System Technologies, Springer Verlag, (2010), 15-26

[9] Pęksiński J., Mikołajczak G., Kowalski J., Using a Neural Network to Generate a FIR Filter to Improves Digital Images Using a Discrete Convolution Operation, Intelligent Information and Database Systems (ACIIDS 2012), PT II Book Series: Lecture Notes in Artificial Intelligence, 7197, (2012), 294-300

[10] Bloch C., *The HDRI Handbook: High Dynamic Range Imaging for Photographers and CG Artists,* Rocky Nook 2007

Authors:

dr inż. Jakub Pęksiński, dr inż. Grzegorz Mikołajczak, Zachodniopomorski Uniwersytet Technologiczny, Katedra Telekomunikacji i Fotoniki, ul. 26 Kwietnia 10, 71-126 Szczecin, E-mail: jpeksinski@zut.edu.pl; grzegorz.mikolajczak@zut.edu.pl;

dr inż. Janusz Paweł Kowalski, Pomorski Uniwersytet Medyczny, Samodzielna Pracownia Informatyki Medycznej i Badań Jakości Kształcenia, ul. Rybacka 1, 70-204 Szczecin, janus@pum.edu.pl