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A Fully Automatic Stitching of 2D X-ray Images

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Introduction

There are a lot of cases where large images can be created only by stitching several smaller images. Image stitching allows creating panoramic images 135˚×200˚ with a usual photo camera 50˚×35˚. Because of the photo detectors' resolution limitations, photomap image must be registered by stitching big number of smaller images [1]. When acquiring large paper documents possibility to scan them is limited by scanner dimensions [2]. In the modern medicine, today, it is usual to employ computer diagnostic methods [3-5]. Anyway, on large size X-ray image registration, essential limitations are brought by the cost of the equipment, directly related to its complexity and size.

Stitching one big and seamless image from several smaller images requires precise knowledge of image fragment disposition between each other. This is the only case when images can be stitched without seams. There are two ways to achieve the same result:

1) register image fragments as precise as possible and stitch them relying only on registration parameters;
2) register overlapping image fragments less precisely, and calculate parameters required for stitching using information located in the overlapping image regions.

The first method requires technical equipment with high precision. Despite of that, according to [6], when stitching fragments in this way it is hardly possible to avoid image segmentation. Second method can be used with cheaper and less complex technical equipment, but in this case it is required process information from the overlapped image regions. Considering the cost and computing power of the modern computational equipment, the second method, today, is more attractive.

Formulation of the problem

The image stitching process can be divided into four steps:

1) detector positioning;
2) image registration;
3) image parameter calculation;
4) parameter tuning and image merging.

At first sight algorithm looks simple, but the third step "image parameter calculation" is far from being trivial. Stitching requires image parameters such as rotation angle, scale or disposition. To make calculation of these parameters possible, the same objects in the overlapping image region must be identified. In the real application images are very different. Identification of the same object in two images is problematic. For example, aerial images have a lot of sharp objects, but medical X-ray images have only blurred contours. Even when images do have sharp objects, without having a-priori information about them, there is no assurance that identified object in both images is the same.

Discussed problems, makes the fully automatic image stitching impossible. Sooner or later an error will arise and the image stitching process will require a human intervention.

This problem can be eliminated by adding additional a-priori information into the image [7]. This action must be performed earlier than image registration. This means, that artificial markers must be superimposed on the images. Markers should be chosen according to the objective to calculate stitching parameters fully automatically. Complexity of the superimpose operation depends on the image nature. In the photomap creation such operation is too expensive, because objects being registered in this case are very large and adding artificial markers means placing them in big distances between each other. Also, they should be big and bright enough to be recognized in the registered image.

It is much simpler to superimpose artificial markers on the images where detector is close to the registration object. One of the ways to add a priori information to the image fragments is described in the [8], where medical X-ray images are being stitched using artificial markers form the metal grid of perpendicular lines. Method allows making the stitching process fully automatic, but it also has one major weakness: the whole stitched image contains superimposed grid. This is an artificially created image distortion, which downgrades image quality.

This paper proposes an alternative medical X-ray image stitching method allowing fully automatic image stitching without adding artificial distortion as a side effect.

The method of the fully automatic image stitching

Fully automatic image stitching requires artificial markers to be superimposed on the image. Artificial marker should:
1) be easily and precisely detectable;
2) allow to calculate stitching parameters;
3) allow calculate the value of every parameter independently from other parameters;
4) allow removing them from the image without leaving any distortion.

For medical X-ray image stitching, listed requirements could be met by a metal (or other material sensitive to the X-ray radiation) strip, placed near the object being registered. The shape of the strip is shown in the Fig. 1.

Fig. 1. Artificial marker strip

The strip should be placed near the object, which should be registered. After image registration and stitching operations the strip can be removed from the image without any subsequences. Metal objects in the X-ray images always have higher, than human body parts, intensity. This means, that strip can be easily detected in the image.

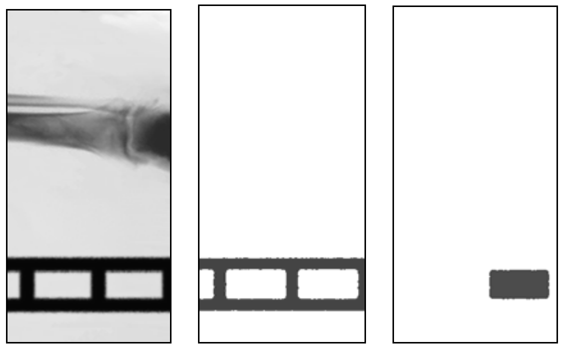
The angle of the image rotation can be calculated according to the orientation of the rectangles in the strip. Even more, the exact angle can be calculated independently from the image scale [9]. Image scale can be calculated according to area of the rectangles in the strip.

During image registration, the strip must be placed near the object being registered (the hand, the leg or even the whole human body). The strip shouldn't be shorter than the registration object. During registration of all image fragments, the strip and the registration object should remain still. Image fragments must have at least 20 % overlapping. When stitching images in these conditions, required calculations are:
1) detect rectangle from the metal strip shape in the image;
2) calculate the rotation angle of the rectangle;
3) calculate the scale of the rectangle;
4) unify scale and angle in the all image fragments;
5) calculate image fragment disposition;
6) join all image fragments according to disposition.

In this case images are stitched using complex direct/feature based stitching method. The calculation of the rotation angle and scale is based on the artificial markers superimposed on the image (feature based method). Image fragment displacement is detected calculating the correlation (direct method). Direct methods are much slower, but also more precise and reliable.

Detecting rectangles in the shape of metal strip

Metal strip in the X-ray image will always be more intensive, than human body parts. In the Fig. 2, it is visible how metal strip looks like in the inverted radiograph. This feature allows detecting the shape of the strip using a simple threshold function, which divides image into two regions: region with high intensity (corresponding to black color) and region with low intensity (white color). After threshold function image has two sharp regions. One region is the shape of the strip and the other corresponds to background (Fig. 2, b).



a) b) c)

Fig. 2. Rectangle detection in the X-ray image

Detection of the rightmost rectangle in the threshold image is based on solid intensity region filling algorithm:
1) Regions in the top and in the bottom of the image are filled with the strip shape color. After this action image contains only rectangles from the strip shape.
2) If the rightmost rectangle is connected to the right edge of the image, this rectangle is also filled with the strip shape color.
3) Detected the rightmost, not connected to the right edge of the image, rectangle

Rectangle, detected from the shape of the strip in X-ray image, is shown in the Fig. 2, c. This rectangle already can be used for of the image fragment angle or scale detection

Fragment rotation angle calculation

Automatic rotation angle detection becomes possible when a metal strip having special form (Fig. 1) is included in the X-ray image. To detect the rotation angle in such images it is enough to detect rotation angle of the rectangle from the strip shape. For this purpose algorithm given in [9] can be used.

Calculation is based on the Fourier transformation of the rectangle, detected in the strip shape.

Proposed methodic will be applied on the digital X-ray images. Digital radiograph is a low contrast two-dimensional image $x_{M\times N}$:

$$x_{M\times N} = \begin{bmatrix} x_{0,0} & x_{1,0} & \cdots & x_{m,0} & \cdots & x_{M-1,0} \\ x_{0,1} & x_{1,1} & \cdots & x_{m,1} & \cdots & x_{M-1,1} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{0,n} & x_{1,n} & \cdots & x_{m,n} & \cdots & x_{M-1,n} \\ \cdots & \cdots & \cdots & \cdots & \cdots & \cdots \\ x_{0,N-1} & x_{1,N-1} & \cdots & x_{m,N-1} & \cdots & x_{M-1,N-1} \end{bmatrix}; \qquad (1)$$

where $x_{m,n}$ – intensity value of the radiograph pixel; $m = 0, 1, 2,...,M-1$, $n = 0, 1, 2,...,N-1$ – image pixel coordinates; M – number of pixels in the image row; N – number of pixels in the image column.

The coefficients of the direct Fourier transform applied on the radiograph $x_{N\times M}$ are calculated according to this equation:

$$X_{p,q} = \sum_{m=0}^{M-1}\left(w_M^{pm} \sum_{n=0}^{N-1}\left(w_N^{qn} x_{m,n}\right)\right); \qquad (2)$$

where $p = 0, 1, 2,...,M-1$, $q = 0, 1, 2,...,N-1$ – the coordinates of the Fourier transform coefficient; w_M = exp(–j2π / M) – phase multiplier for a step in a row, w_N = exp(–j2π / N) – phase multiplier for a step in a column, M – number of pixels in the row of the Fourier transform image; N – number of pixels in the column of the Fourier transform image.

Calculated array of the Fourier transformation coefficients is complex. Every coefficient $X_{p,q}$ has its real Re[$X_{p,q}$] and imaginary Im[$X_{p,q}$] parts. Rectangle's rotation angle is determined by transformation's amplitude spectrum. For this purpose, a modulus $|X_{p,q}|$ of the Fourier coefficients in the array is calculated:

$$\left|X_{p,q}\right| = \sqrt{\left(\mathrm{Re}[X_{p,q}]\right)^2 + \left(\mathrm{Im}[X_{p,q}]\right)^2}\,. \qquad (3)$$

Fourier coefficient modulus matrix calculated using (3) has big differences between coefficient values. A small region of high intensity coefficients can drown the meaning of all other image elements. Influence of these differences can be minimized by converting every coefficient modulus in the matrix to logarithmic form $|X_{p,q}|$, db:

$$X_{p,q}\text{, db} = 20 \log |X_{p,q}|. \qquad (4)$$

Image of the rectangle detected in the digital X-ray image (256×256 8 bit greyscale) rotated by 35° angle is shown in the Fig. 3. The image of the Fourier transformation coefficient logarithmic modulus is given in the Fig. 4 (256×256 8 bit greyscale). In this image, darker regions correspond to higher coefficient values. The branches in the Fig. 4 represent the rectangle's rotation angle.

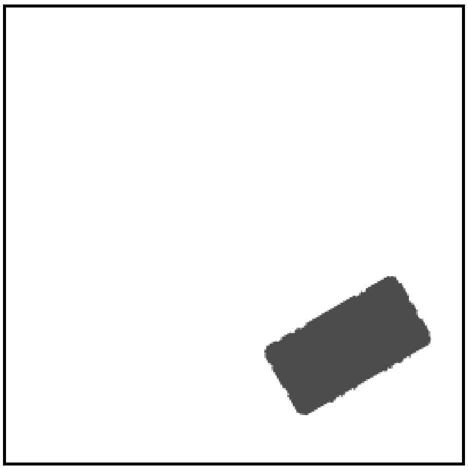


Fig. 3. Rotated rectangle detected in the digital radiograph image

To calculate the rotation angle, $|X_{p,q}|$, db matrix must be centred. Intensity maxima must be moved from image's edges to its centre. This means substituting image quadrants: first with third and second with fourth. This operation is described by such equation:

$$\begin{cases} p_c = p + M/2, \text{ if } 0 \le p \le M/2, \\ q_c = q + N/2, \text{ if } 0 \le q \le N/2, \end{cases}$$
$$\begin{cases} p_c = p - M/2, \text{ if } M/2 \le p \le M, \\ q_c = q + N/2, \text{ if } 0 \le q \le N/2, \end{cases}$$
$$\begin{cases} p_c = p + M/2, \text{ if } 0 \le p \le M/2, \\ q_c = q - N/2, \text{ if } N/2 \le q \le N, \end{cases} \qquad (5)$$
$$\begin{cases} p_c = p - M/2, \text{ if } M/2 \le p \le M, \\ q_c = q - N/2, \text{ if } N/2 \le q \le N. \end{cases}$$

After coefficient matrix centering operation, image becomes symmetric regarding centre (Fig. 6.). The image has four clearly visible branches. Two of them, the brightest ones, have the same rotation angle as the rectangle itself. So, the image rotation angle can be identified be detecting the rotation angle of the described branch. This is done by converting image to the polar coordinate system.

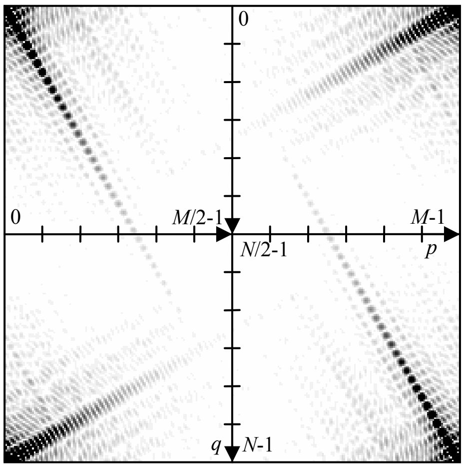


Fig. 4. Fourier transformation of the rotated rectangle

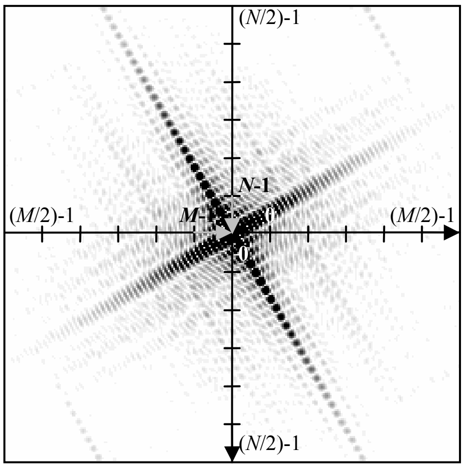


Fig. 5. Fourier transformation of the rotated rectangle after centering operation

For this purpose the origin of the coordinate system is shifted to the image centre:

$$N_0 = N/2,\ M_0 = M/2. \qquad (6)$$

According to the new origin, the angles of every coefficient pixel in the image are calculated:

$$\Theta = \begin{cases} \arctan(\Delta p/\Delta q), & \text{if} \quad \Delta p > 0 \quad \text{and} \quad \Delta q \geq 0 \\ \arctan(\Delta p/\Delta q) + 2\pi, & \text{if} \quad \Delta p > 0 \quad \text{and} \quad \Delta q < 0 \\ \arctan(\Delta p/\Delta q) + \pi, & \text{if} \quad \Delta p < 0 \\ \pi/2, & \text{if} \quad \Delta p = 0 \quad \text{and} \quad \Delta q > 0 \\ 3\pi/2, & \text{if} \quad \Delta p = 0 \quad \text{and} \quad \Delta q < 0 \end{cases} \qquad (7)$$

where $\Delta p = (M_0 - p)$ – pixels distance from the centre in a row; $\Delta q = (N_0 - q)$ – pixels distance from the centre in a column.

Intensities of the coefficient pixels having the same angle range are summarized. This action builds an array having element count defined by number of angle ranges. Every element in this array represents summarized intensities of the Fourier coefficient pixels rotated, regarding centre, with the same angle. Example of such array is shown in the Fig. 6.

Finally, image rotation angle is determined by the array element, having the highest value.

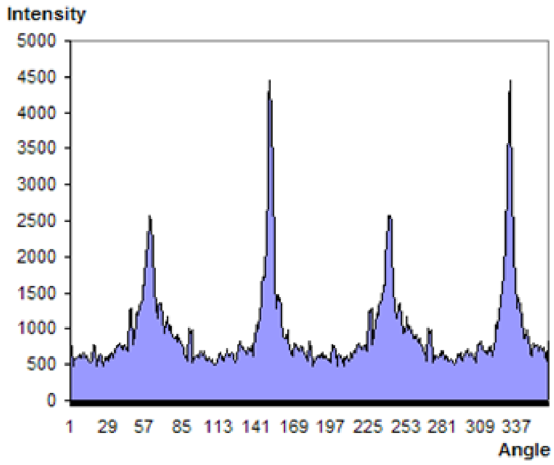


Fig. 6. Fourier transform coefficient values summarized according to angle ranges

The accuracy of the detected angle depends on image resolution and the count of the angle ranges, according to which intensities were summarized during previous step. Requiring 0.5° angle detection accuracy – 360 ranges are required (360 array elements). Increasing accuracy to 0.1 – element count must be upgraded to 1800.

When angle is detected all image fragments must be aligned according to the long wall of the strip rectangle. Aligning fragments in such manner will cause final, stitched image to be aligned according to the strip.

Fragment scale calculation

Fragment scale is proportional to the area of detected strip rectangle. In the Fig. 2, c there are only two intensity levels. One of them represents the rectangle, other – the background. To calculate the area of the rectangle, all pixels representing its intensity must be calculated. Performing fragment scale unification, areas of the each rectangle in each fragment should become equal.

Image disposition calculation

Image fragment disposition is determined using calculation of the shifted image correlation. To make it possible before the calculation fragments must be modified to have the same scale and rotation angle. When biggest possible horizontal fragment overlapping is 20%, correlation should be calculated for the 30% of image overlap. Images also can be shifted in vertical direction. This means that correlation for vertically shifted images must be calculated. If the vertical shift limit during detection is 20% it will be enough to calculate correlation for images shifted 30% to the top and 30% to the bottom. Region, where possible image disposition should be searched, is displayed in the Fig. 7.

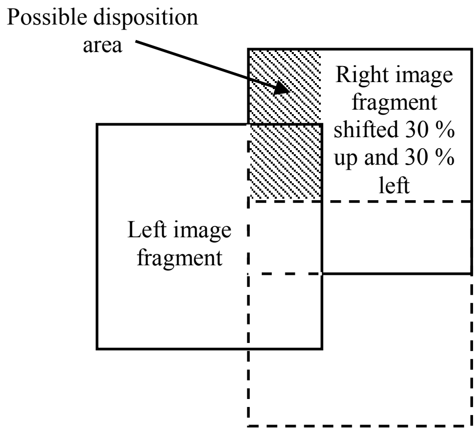


Fig. 7. Possible image disposition area

Seeking disposition point according to listed conditions, search will have to be performed in the possible disposition pixel set S, which is described by the row and column pixel counts by following equation:

$$S = 0.3M \times 0.6N. \qquad (8)$$

Correlation d_s must be calculated for every possible image fragment disposition, in the area where fragments are overlapping:

$$d_s = \sum_{O_s} (x_1 - x_2)^2 = \sum_{O_s} \left(x_1^2 - 2x_1x_2 + x_2^2\right); \qquad (9)$$

where: s – analyzed image fragment disposition; O_s – set of overlapping pixels at fragment disposition s; x_1 – pixel from the set O_s of the image which is being stitched with another image from the right; x_2 – pixel from the set O_s of the image which is being stitched with another image from the left;

From (9) it visible, that the value of d_s will be small when x_1 and x_2 are almost identical and large when they differ significantly. But correlation calculated using (9) has one major disadvantage: the value of d_s depends on the size of overlapping area. Problem can be solved by using normalized correlation:

$$d_n = \frac{\sum_{O_s}(2x_1x_2)}{\sqrt{\sum_{O_s}(x_1)}\sqrt{\sum_{O_s}(x_2)}}. \quad (10)$$

After correlation is calculated in the whole search area S, exact fragment disposition point can be identified by finding the highest correlation value.

When exact disposition point is known, the last operation to do is join two image fragments using given disposition.

Stitching two image fragments

Even after aligning exact image fragment rotation angle, scale and disposition, fragments can‘t be just placed one on another because after such operation clearly visible seam will appear in the stitched image. It is shown in the Fig. 8.

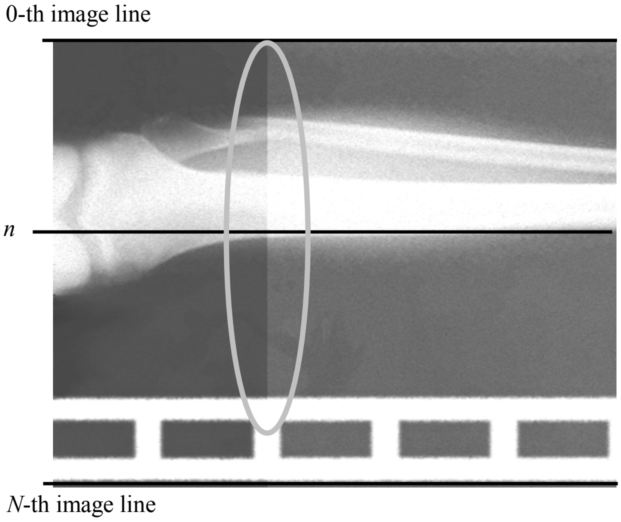


Fig. 8. Stitched image (without blending)

Stitching line is marked with a gray oval. In the Fig. 8 this line is clearly visible. The cause of this visible seam first of all is different mean intensity in left and right image fragments. Described method doesn‘t perform intensity adjusting. However even after mean intensity justification the seam will slip out because of an accidental mistake or scale / rotation angle recalculation error. In the Fig. 8 this line is artificially revealed, usually it is not so bright, but complete line removal is possible only when stitching line blending operation is used.

Stitching seam blending for the image line n is described by this equation:

$$x_{Sn}(m) = x^L_{Sn}(m)\cdot b^L(m) + x^R_{Sn}(m)\cdot b^R(m); \quad (11)$$

where: x_S(m) – intensity of the m-th pixel in the n-th line in the stitched image; $x^L_{Sn}(m)$ – intensity of the m-th pixel in the n-th line of, expanded to the stitched image size, the left image fragment (Fig. 9c); $x^R_{Sn}(m)$ – intensity of the m-th pixel in the n-th line of, expanded to the stitched image size, the right image fragment (Fig. 9d); b^L – the value of the blending function for the m-th pixel of the left image fragment (Fig. 9a); b^R – the value of the blending function for the m-th pixel of the right image fragment (Fig. 9b);

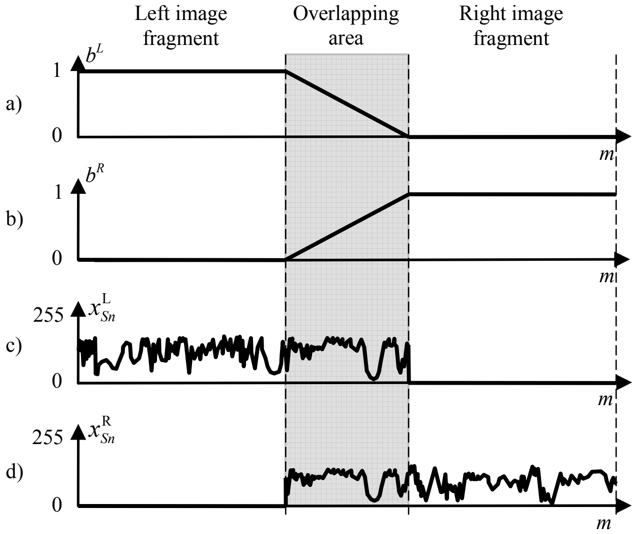


Fig. 9. Blending functions and image fragment line pixel intensities

When blending functions are used to perform stitching, weighted pixel intensities from overlapping fragment area are summed. Weight of left image fragment pixel intensities are linearly gradually reduced and intensities from right fragment - gradually enlarged. Stitching images in such manner extends stitching line through the whole overlapping area and stitching consequences becomes hardly noticeable.

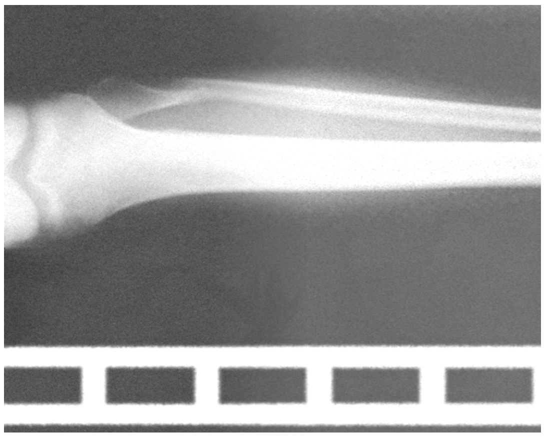


Fig. 10. Stitched image with blended stitching line

Even when image fragments shown in the Fig. 10 are distorted with intention (added random noise and changed mean intensity), after stitching with blending result image does not contain any seams.

Conclusions

1. Fully automatic image stitching requires artificial markers to be superimposed on the image.

2. When a metal strip, with rectangular holes in it, is used in the image as an artificial marker, image rotation angle, scale and fragment disposition can be detected fully automatically.

3. Easiest way to detect the rotation angle of the image is to calculate the spectrum of the rectangular hole in the shape of the metal strip.

4. Scale, in the image fragments, can be detected calculating the area of rectangle located in the shape of the metal strip.

5. Stitching operation must be performed only after scale and rotation angle unification in the image fragments. Images are joined according to the calculated disposition. The disposition is identified calculating correlation, in the overlapped image area.

6. Because of the different noises, which arise during image registration, the seam is visible at the stitching line. Seams become hardly noticeable when images are stitched with blending. Blending expands stitching line all trough the fragment overlap area.

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Problems of the stitching one big image out of several smaller image fragments are being solved in this paper. Proposed methodic, for the fully automatic stitching of two-dimensional computer radiographs. Methodic is based on the requirement to have additional information about scale and rotation angle in the image fragments to be stitched. Proposed to add marker information into radiograph, by placing a sturdy metal strip having rectangular holes, near the object being observed, during image fragment registration. The method allows identifying image parameters required for the seamless stitching according to the rectangular holes detected from the strip shape and joining image fragments in a fully automatic manner. Method implementation is described. Problems of the fragment parameters' – rotation angle, scale and disposition identification are being solved. Presented algorithm for radiographs rotation angle calculation using Fourier transform and its verification results. Ill. 10, bibl. 9 (in English; summaries in English, Russian and Lithuanian).

Д. Матейка, Р. Мартавичюс. Полностью автоматизированное объединение двухмерных компьютерных рентгенограмм // Электроника и электротехника. – Каунас: Технология, 2007. – № 8(80). – С. 3–8.

Решаются проблемы автоматического объединения нескольких небольших изображений одного объекта в одно большое изображение. Предложена методика полностью автоматизированного объединения двумерных компьютерных рентгенограмм. Методика основана на требовании введения в небольшие объединяемые изображения информации о масштабах и углах взаимного поворота изображений. Упомянутую информацию предлагается вводить во время создания небольших рентгенограмм путем помещения на фоне исследуемого объекта металлической полоски с прямоугольными отверстиями. Предложенный метод позволяет после выделения из рентгенограмм изображений прямоугольных отверстий получить всю необходимую информацию о взаимном положении изображений и автоматически их объединить. Приводится описание реализации метода. Анализируется решение задач для получения параметров, необходимых для объединения рентгенограмм, – угла поворота, масштаба и яркости. Приводится алгоритм определения угла поворота рентгенограмм, основанный на Фурье преобразовании, и результаты его проверки. Ил. 10, библ. 9 (на английском языке; рефераты на английском, русском и литовском яз.).

D. Mateika, R. Martavičius. Visiškai automatizuotas dvimačių kompiuterinių rentgenogramų sujungimas // Elektronika ir elektrotechnika. – Kaunas: Technologija, 2007. – Nr. 8(80). – P. 3–8.

Sprendžiamos vieno objekto kelių mažų vaizdų automatinio sujungimo į vieną didelį vaizdą problemos. Siūloma visiškai automatizuoto dvimačių kompiuterinių rentgenogramų sujungimo metodika, pagrįsta reikalavimu turėti mažesniuose vaizduose informaciją apie sujungiamų vaizdų mastelio pokyčius ir jų tarpusavio posūkius. Tokiai informacijai į rentgenogramas įterpti siūloma mažesniųjų rentgenogramų atlikimo metu tiriamojo objekto fone padėti stangrią metalinę juostelę su stačiakampėmis kiaurymėmis. Pasiūlytas metodas leidžia, išskyrus iš rentgenogramų stačiakampių kiaurymių vaizdus, gauti visus reikiamus duomenis apie sujungiamų vaizdų skirtingą padėtį ir juos automatiškai sujungti. Aprašomas metodo įgyvendinimas. Sprendžiami rentgenogramoms sujungti reikalingų vaizdų parametrų – pasukimo kampo, mastelio ir vaizdo šviesumo – nustatymo uždaviniai. Pateikiamas rentgenogramos vaizdo pasukimo kampo nustatymo, taikant Furjė transformaciją, algoritmas ir jo patikrinimo rezultatai. Il. 10, bibl. 9 (anglų kalba; santraukos anglų, rusų ir lietuvių k.).