Low-Cost Digitalization of X-ray Films Using a Scanner and an Image Stitching Algorithm

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Abstract *– This paper outlines the technical and algorithmic details of a fast low cost method for the digitalization of X-ray films of all standard sizes. In order to keep costs low, a standard A4 size scanner with transparency media adapter was used. Since most X-ray films are larger than the A4 size image capturing area of the scanner, this necessitated the development of an image processing algorithm that could stitch two or four partial images of the whole X-ray film, depending on its size, into a seamless full image of the film. The proposed image stitching algorithm produces high resolution seamless images with good contrast and quality that permits their use in a tele-radiology project, which is the final goal.*

Resumo *– Este artigo esboça os detalhes técnicos e algorítmicos de um método rápido e de baixo custo para a digitalização de filmes radiográficos de todos os tamanhos padronizados. A fim de manter o custo baixo, optou-se pela utilização de um scanner com adaptador para mídia transparente de tamanho A4. Como a maioria de filmes radiográficos é maior do que o tamanho da área de captura de imagens de um scanner tipo A4, isto necessitou o desenvolvimento de um algoritmo de processamento de imagens que pudesse costurar duas ou quatro imagens parciais do filme inteiro, dependendo do seu tamanho, para produzir uma imagem do filme inteiro sem sutura visível. O algoritmo final proposto obtém imagens de alta resolução, com bom contraste e uma alta qualidade de costura, permitindo a utilização delas em um projeto de tele-radiologia, que é a meta final.*

1. Introduction

This paper describes a low cost process for the digitalization of X-ray films that was developed in the context of a teleradiology project called Teleintegration for X-Ray Images (TIPIRX) funded by FINEP, the Brazilian Innovation Agency for Research and Project Financing. The main project goal is to provide a low cost solution to the problem of lack of radiologists in remote areas, by providing a method to digitalize conventional X-ray films of patients in remote areas and transmit them to teleradiology centers via Internet, where qualified radiologists can provide second opinions, which are then returned to the remote areas by Internet. The teleradiology scheme is part of a broader telehealth initiative funded by the Brazilian Health Ministry and the X-ray digitalization process described in this paper will eventually be included in the telehealth kit (desktop computer with Internet connectivity, printer and A4 flatbed scanner).

This paper will concentrate on the technical and algorithmic details of the digitalization process, which drives the ScanRx software user-friendly interface, described elsewhere.

2. Flatbed scanners with transparency media adapters

This section briefly describes flatbed scanners with transparency media adapters (TMAs) and some of their limitations that had an impact on the method described in this paper.

2.1 Image capture area size limitation

The main class of chest X-ray films that are the focus of the teleradiology project mentioned above are post-anterior thorax and profile films which come in 3 standard sizes, namely 30×40, 35×35 and 35×43 cm. However, the vast majority of low cost commercial flatbed scanners with TMAs have a scan or image capture area limited to A4 size (21×29.7 cm), which makes it impossible to digitalize (scan) an entire X-ray film at one go. This implies that, if an A4 size scanner is to be used, then partial images must be acquired in such a way as to make it possible to stitch two or more of them into the whole image.

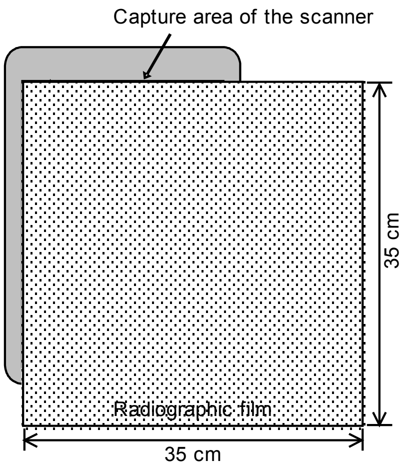

Figure 1. Showing A4 scanner image capture area in comparison with the larger shaded area of one standard X-ray film size (35 by 35 cm).

2.2 Scanners with transparency media adapters (TMA)

A common flatbed or desktop scanner uses a CCD array to capture the light reflected from the opaque target placed on the glass plate. A scanner with TMA, on the other hand (see Fig. 2), uses a scan head with a lamp that illuminates the transparent medium from above, while the sensor is located below the glass plate

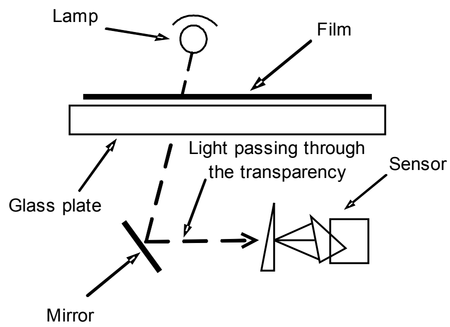

Figure 2. How a scanner with a transparency media adapter (TMA) works.

2.3 Choice of an appropriate scanner

The simplest choice of scanner to digitalize X-ray films with acceptable quality would be to use a medical image digitizer that is designed to scan large format objects, such as X-ray films. The price of such digitizers is, however, about eight times that of an A4 size scanner that is able to produce images of comparable quality, except that they are limited to A4 size [1].

3. Basics of Image Stitching Using Template Matching

An image is treated in the standard fashion as an m by n matrix, with each element representing an 8-bit pixel (256 level grayscale). Some standard terminology from the area of image stitching is now defined. The *overlapping area*, between two partial images, A and B, of a larger image, is the area in common between them (see Figure 3). The next step is to choose one of the partial images and, within the overlapping area of this image, choose a *comparison area* (also called a *sensitive area*) or *template* (Fig. 3). The comparison template is generally a small subregion of the overlapping area and is chosen in accordance with the following criteria: (i) it should not be chosen in a region where most pixels have the same grayscale level, which is quite a common occurrence in X-ray films, which have large dark areas (corresponding to soft tissue) and white areas (corresponding to denser structures such as bones); (ii) the computational tradeoff between the level of detail (i.e., number of distinct features) and the time taken by the algorithm to find a matching template in the target image (B) search area. The larger the number of features, the higher the chance of a successful matching, but the total computational time is also proportionally higher. In the proposed algorithm, the choice of a comparison area is based on the histogram (number of pixels of each grayscale level) of a candidate area (see Fig. 4). In practice, the *variance* of the grayscale distribution of the pixels was found to be an adequate measure of the concentration of pixels in a small interval of grayscale level values:

$$\sigma^2 = \frac{1}{N}\sum_{i=0}^{N}(y_i - \mu)^2 \qquad (1)$$

where σ^2 is the variance, N = 255, y are the pixel grayscale values and μ is the mean pixel grayscale value.

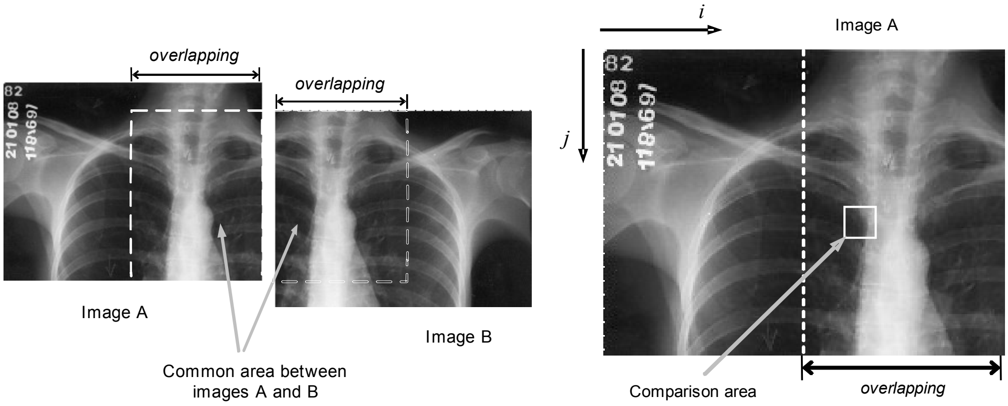

Figure 3. Overlapping area between partial images A and B of a larger image [left] and comparison area within overlapping area of image A [right].

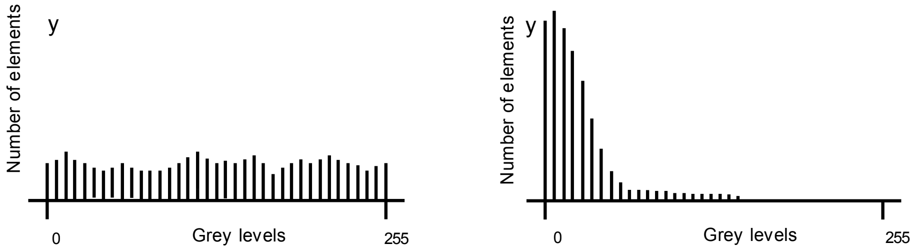

Figure 4. Histograms of areas containing several grey levels (desirable) [left], and of a dark area (few grey levels, undesirable)[right] .

3.1 Search area

The search area is a sub-area of the overlapping area in the target image B in which it is hoped to find the best match to the comparison template (from A), since it is in this region that the comparison template should be replicated. The size of this region is one of the main factors that determine the speed of the stitching algorithm.

In principle, the search area could be chosen to be the entire overlapping area, but further narrowing down of the area is possible, using the known information of image capture area and location of the scanner as well as the (user supplied) extra information of X-ray film size (see Fig. 5).

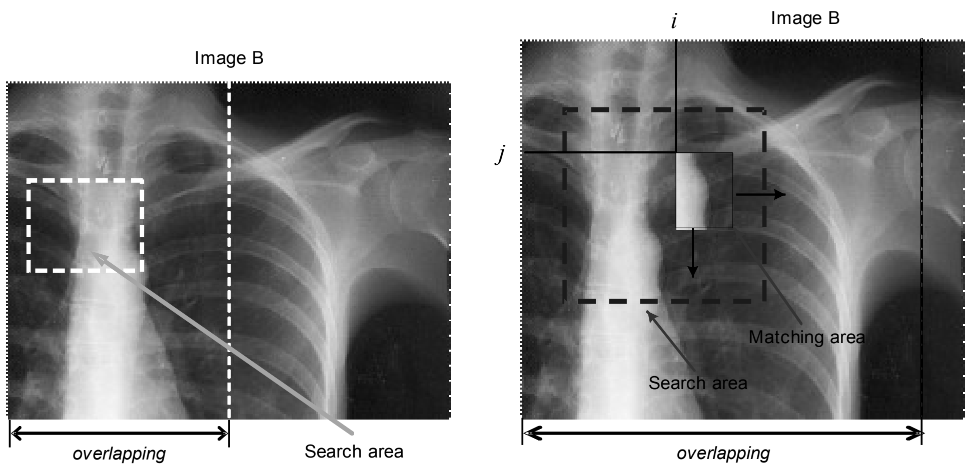

Figure 5. Search area in overlapping target region of image B [left]; showing how the comparison template sweeps the search area to find the matching area [right].

In order to determine the optimal search area, it is assumed that the partial images are obtained with perfect vertical alignment, which is a reasonable assumption, given the protocol that is to be followed in their acquisition (straight edges of x-ray film are aligned with the straight edges of the scanner glass plate frame). Then, using the information on film size, scan capture area and number of pixels per inch (scanner resolution), it is possible to work out the exact width of the overlapping area and its dimension in pixels, as well as the coordinates of the comparison area. The optimal search area is then calculated by adding margins to the comparison area coordinates, where the margins are found by using the largest horizontal and vertical displacements, with respect to partial image A, that occur when positioning the second partial image B on the glass plate of the scanner. These margins, which are adjusted experimentally, are set to achieve a high probability of successful matching without too large a computational cost.

3.2 Matching criterion

Once the comparison template and optimal search areas have been found, as described above, the next stage is to define a matching criterion for the degree of similarity between the comparison template and an area of the same size as the template taken from the search area successively, by an exhaustive sweep.

The similarity measure chosen for template matching was the root of grayscale average difference (RGAD) [2,3], which is defined in the following paragraph.

Consider two images defined as:

$$A = \{a_{ij}\}_{m \times n}, B = \{b_{ij}\}_{m \times n}$$

The difference image Δ is defined as the matrix:

$$\Delta_{m \times n} = \{a_{ij} - b_{ij}\}_{m \times n}$$

The *grayscale average difference* is defined as:

$$G_{av} = \left(\sum_{i=1, j=1}^{i=m, j=n} \Delta_{ij} \right) / (m \times n)$$

Finally the RGAD is defined as:

$$J = \sqrt{[\sum_{i=1,j=1}^{i=m,j=n} (\Delta_{ij} - G_{av})^2]/(m \times n)} \qquad (2)$$

Clearly, the lower the value of the RGAD, the more similar are the images corresponding to the matrices *A* and *B*. The proposed algorithm carries out a sweep of the search area (fig. 5) in blocks of the size of the comparison template, computing the RGAD of each block in order to find the coordinate position of the matching template block with the least RGAD .

3.3 Image stitching

Once the coordinates of the matching template have been found, it is straightforward to calculate the offset that causes the superposition of images A and B in such a way that the search and matching templates coincide exactly. This process results in a seamless stitched image composed of the partial images A and B (Figure 6). Further details, involving corrections of tilted images as well as the "smoothing of the seam" (to achieve seamlessness) are omitted here and can be found in a Master's thesis [3].

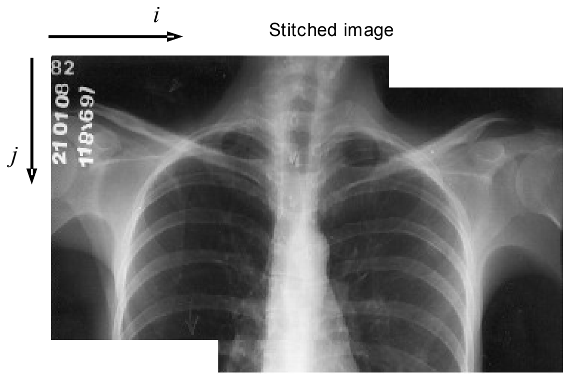

Figure 6. A stitched image generated from two partial images.

4. Flow Chart of the Image Stitching Algorithm

The stitching process described above was applied to large X-ray films (e.g., 35cm by 43 cm) for which 4 partial images are scanned, so that the stitching process has to be aplied three times (to upper left and right halves, to lower left and right halves, and finally to the two latter results). The flow chart of the complete algorithm is given below for the reader's convenience.

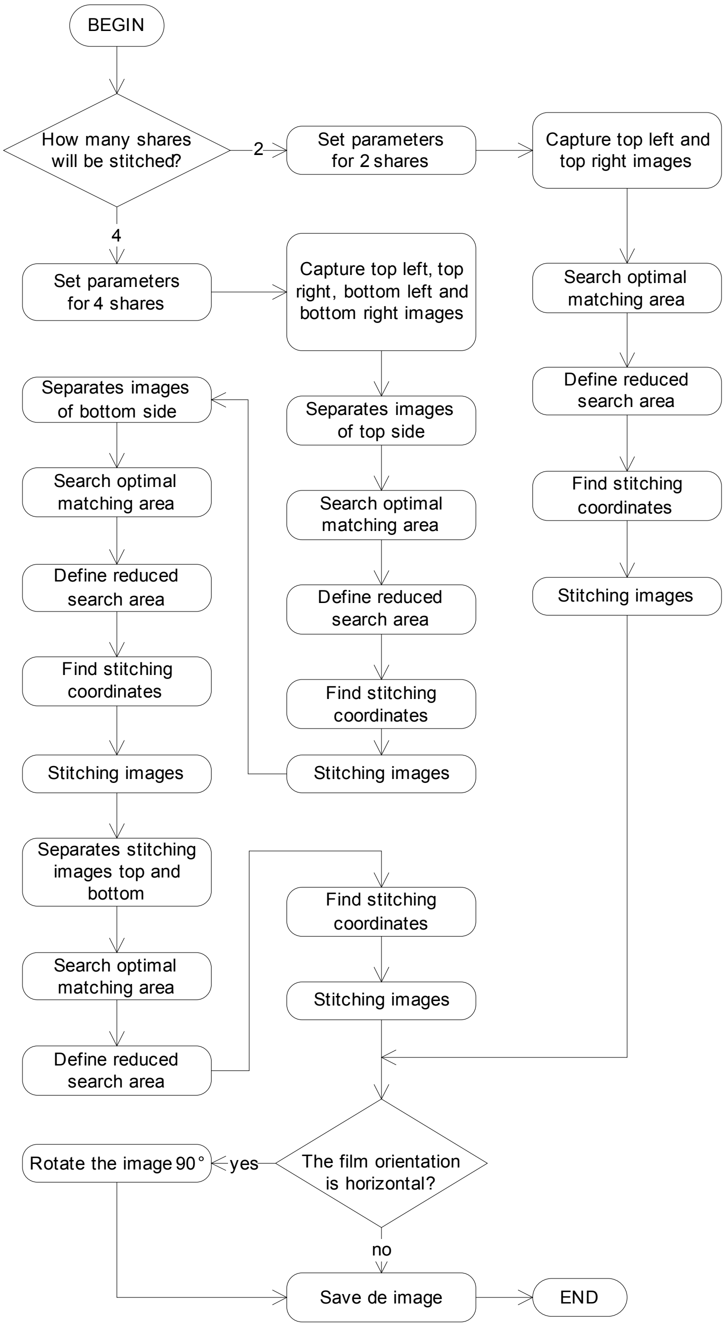

Figure 7. Flow chart of the complete image stitching algorithm.

Finally, the parameters and technical specifications of the equipment used are as follows: X-ray film dimensions: 30×40, 35×35 e 35×43 cm; Scanner used: Microtek ScanMaker i800; Scanner capture area: 20.32×30.48 cm; Capture resolution: 180dpi ou 5022 pixels/cm$^{2;}$ Maximum number of partial images: 4; Size of each partial image: 1453×2163 pixels; Size of comparison area: 80×80 pixels; Size of search region: 300×600 pixels

5. Experimental Results

The experimental results below were carried out on a personal computer with an AMD 3800 processor with a 2.4 GHz clock and 1 GB of RAM. The table shows the execution times for the whole image stitching algorithm for three largest X-ray film sizes, for each of which 4 partial images and three stitching processes are required.

The execution times shown in Table 1 do not include the time taken by the scanner to acquire the partial images: these acquisition times are one order of magnitude higher than the stitching times, since the acquisition process is a relatively slow electromechanical process.

Table 1. Image stitching times for different X-ray film sizes

Film Dimensions (cm)	Time (s)	Final image size (in pixels)
30 × 40	6,21	1477×2941
35 × 35	7,32	2557×2593
35 × 43	8,15	2557×3042

Figure 8 shows the result of the image stitching digitalization algorithm applied to a 35cm×35cm X-ray film. This film was scanned in four parts which were then stitched together using the algorithm described above.

Figure 8. Final result of the image stitching digitalization algorithm of a 35cm×35cm X-ray film.

6. Conclusions

The algorithm described above was used to digitalize a large number of X-ray films from three large University Hospital archives and subjected to standard statistical tests for validation, described in detail in the present context in [8, 9]. The overall evaluation was positive in terms of the quality of the digitalization, from the point of view of resolution, as well as non-appearance of artefacts as a consequence of the scanning (image acquisition) and stitching algorithms. These results, outside the scope of this conference, are also described elsewhere. The current state of the TIPIRX project, under which the present algorithm was developed, is the installation of teleradiology kits in several remote municipalities of the State of Rio de Janeiro, in which qualified radiological evaluation is required but unavailable, so that second opinions using the proposed system for digitalization is an important first step.

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