A CUDA based digital X-ray image stitching algorithm

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Abstract—**To spare the high cost of an extra-large detector for full body length X-ray imaging, this paper presents a digital X-ray image stitching algorithm. This algorithm uses a stitching process to generate a full body length image by merging multiple images captured from a common dimensioned detector. The algorithm can also provide a less distorted outcome with better image quality. Moreover, it tackles the problem of long processing time of other stitching algorithms, to reduce patient waiting time. CUDA is proved to be an effective measure to be used in the imaging algorithm to reduce the processing time for image stitching. A number of clinical tests have been conducted to verify this method and the results show that the digital X-ray image stitching algorithm presented in this paper is accurate, and can markedly improve patients waiting time when a full-body-length image is needed in clinical applications.**

I. Introduction

In X-ray imaging, digital radiography has the advantages of higher resolution, a broader grayscale spectrum, and contains a higher volume of imaging information over conventional radiography; hence it can assist in raising the accuracy of any diagnosis. At the same time, X-ray equipment using digital radiography scans quicker, reduces motion blurring, emits less radiation, and is in general far more flexible and sensitive compared to conventional radiography equipment. Thus, lesser energy is required to obtain an image scan that is satisfactory. For bones structure, cartilaginous joints and soft tissues, digital radiography presents better images compared to conventional radiography. For application in the orthopaedics field, digital radiography X-ray devices play a vital role, especially in the stitching of individual images. It gives a huge advantage to conducting full body scans, as a much smaller equipment can be utilized for capturing and obtaining a full body X-ray image through stitching.

On the other hand, the field of computing which is closely linked with digitalisation is now moving away from "central processing" using a CPU, towards "co-processing" using both CPU and GPU. To allow this new computing standard, the development of CUDA (Computer Unified Device Architecture) technology has speeded up. CUDA is a parallel computing platform based on NVIDIA's Graphics Processor Units (GPU), and as a specialized high performance GPU computing solution, NVIDIA can provide supercomputing functions to any workstations or servers, as well as server clusters running on CPU. As the special attribute of GPU lies in executing data-intensive processes and parallel computing, therefore the CUDA platform is very suitable for work in the image processing domain which requires vast capability in parallel computing.

This paper discusses a type of digital X-ray image stitching algorithm based on the CUDA platform, and this algorithm has been successfully implemented on digital radiography X-ray devices. A large number of clinical tests have also shown, that despite the massive amount of time reduced in computing, the resulting image stitched together are highly accurate. Compared to the conventional method in acquiring a full body scan image, which requires the scanning equipment units to be sized accordingly, the method raised in this paper utilizes individual image scans of various body parts to carry out a seamless stitching, to arrive at a complete full body scan image. This drastically reduces the costs of operation of the X-ray machines, reduces image distortion, raises the image quality of bones structure area imaging, and on a whole effectively improves doctors' diagnosis on the patients' entire body structure and conditions.

II. X-ray Image Stitching Algorithm

A. The Stitching Process

In the stitching process, the probe equipment moves from the patient's head towards the feet, and entirely captures multiple images covering the patient's full body. When the image collection is complete, a stitch positioning ruler identification method is used to detect the precise position of the stitch positioning ruler, resulting in a reconstructed stitched binary image; then, utilizing the scale measurement marked to derive the numerical measurement of the stitches' position; the numerical measurement of an image is then cross-checked with its two neighbouring images, to arrive at a precise relative positioning order; lastly, image registration algorithm is used to merge the photos together, to complete the automated process of stitching together a full body X-ray scan.

B. Stitch Positioning Ruler Identification Measurement

The stitch positioning ruler is an acrylic glass embedded with extremely fine lead as the rulers' lines and numerical markings, which is highly similar to the marginal information of the human bones structure. If conventional edge detection methods are used here, the information of the body's bone structure might cause interference. This paper uses the below method to ensure the correctness of the stitch ruler's binary

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image, as the below illustration shows:

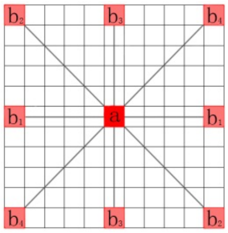

Fig1. Stitch ruler identification diagram

In the binary image, if point A has the value of 1, it has to satisfy the criteria of at least one of the four directions pictured above possessing point A's value, and two observation point B's pixel value satisfying the below relationship:

$$(B-A)/A>\sigma$$

σ as the default threshold,

The stitch ruler message as the below illustration:

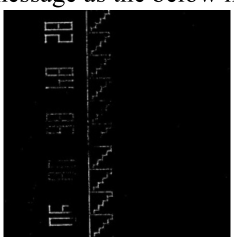

Fig2. Obstruction image of stitch ruler

As can be observed from the illustration, as the stitch ruler is obstructed by the human body, the obstructed regions identification might be suffering some losses, and the stitch ruler mending and reconstructing algorithm proposed later, can automatically adapt to the information partially obstructed.

In the image, any pixel value is confirmed based on the 8 neighbouring pixel values; if any of the neighbouring domain is a non-zero point, the point will be set as 1. After multiple iterative computations, a more complete stitched image composition is formed.

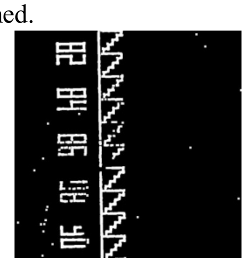

Fig3. Reconstruction image of stitch ruler

C. Marked Scale Identification Algorithm

After a binary image is obtained, there is still a large amount of information that is obstructed. As the ruler is a straight line that runs throughout the entire image, therefore the regions where the line shows the most 1 value points, are where the images overlap and where the stitches will occur, as pictured below:

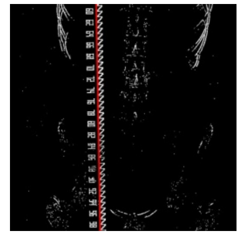

Fig4. Positioning image of stitch ruler

Follow and inspect along the ruler's markings in normal direction, in the specified regions, when the number of 1 value points are larger than the threshold value, that is where the ruler's markings positioned, and where all the measurements can be obtained, as pictured below:

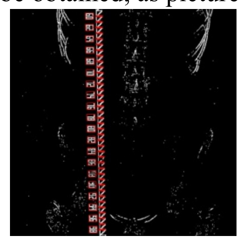

Fig5. Numerical scale image of stitch ruler

D. Marked Scale Comparison Algorithm

Compare all the numerical markings on the scale identified, and where most similarities occur, are positions where the stitch or merges have to take place. As the lined ruler has a certain width, there will definitely be inaccuracies in the stitch identification process. Hence, when carrying out the marked scale comparison process, the best match has to be selected out of all the compared mismatched regions. Hence, the difference between the centres of the two pictures, is the value that the image has to shift in position relatively.

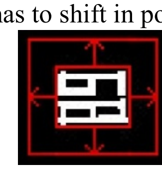

Fig6. Error calibration image of numerical scale

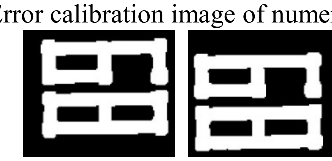

Fig7. Comparison of merged numerical scale before error calibration

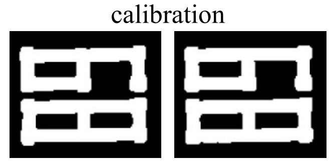

Fig8. Comparison of merged numerical scale after error calibration

E. Image Composition and Merging Algorithm

When the relative shift value needed is obtained, the two images will then be overlapped and merged. As the apparatus' exposure setting is automatically adjusted during the capturing process, the exposure strength will be different at different part of the body, and there will exist differences in the images' grayscale value. At this time the merged image pixel values have to be weighed, from one set of the stitch gradually towards the other, and the resulting processed image is as below:

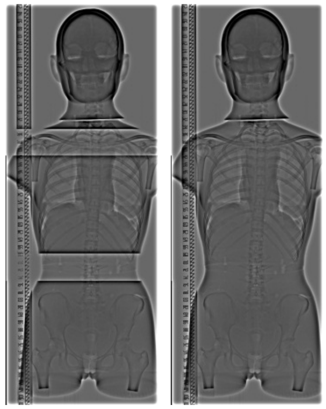

Fig9. Comparison of stitching results with the implementation of image merging algorithm

III. TESTING

The image stitching algorithm has already been applied on the digital radiography X-ray machine XinDongFang 1000D. The equipped computer configuration with this X-ray machine is: CPU: Intel i3 3.3GHz, Memory: 4GB, Graphics Card: Geforce GTS 450, and the testing platform as Microsoft Visual C++ 2005. The images captured were in 14bit, with a 3052*3052 resolution, and there were 3 images to be composed together.

The key components of the merging process is as pictured below

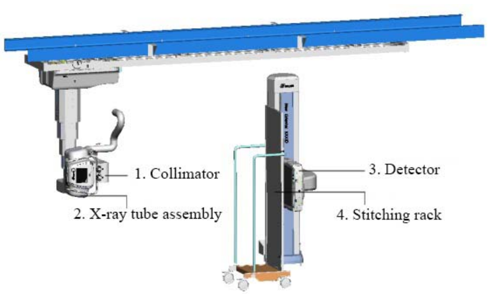

Fig10. Hardware structure of the stitching system

When carrying out the image capturing phase, the patient to be inspected stands on the stitching rack(4), the collimator(1) opens up to completely cover the entire size of the detector(3); the detector(3) shifts to proposed starting point of the scan, and the X-ray tube assembly(2) revolves to track it to ensure that the emission covers the detector(3), to capture the first image. Thereafter, each time the image receiver shifts towards the proposed end-point of the scan. With each gradual repositioning, the X-ray tube assembly(2) revolves to track the image sensor to ensure that the emission covers the image receiver, and multiple images are captured and collected, to provide source images data for the stitching system to function.

The partial result to the stitching is as follows:

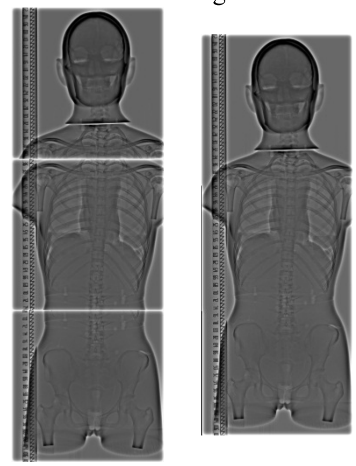

Fig11. Original sampled image and stitched image

As the GPU image matching algorithm utilizes parallel computing technology, 256 threads are used in rendering and computing the image data, and this greatly reduces the time required for calculations. Composes the 100 sets of images to be used in stitching, and results of the CPU computing and GPU computing's calculation time, including the respective longest, shortest, and average computing time, are as follows:

Table 1. Comparison of computing time

	Longest time(ms)	Shortest time(ms)	Average time(ms)
CPU	729	653	689
GPU	130	127	128

IV. CONCLUSION

The medical imaging stitching system discussed in this paper utilizes multiple images of various regions of the body to carry out stitching, to arrive at an accurate and seamless full body length X-ray image. Such stitching system reduces the operating cost of X-ray machines, is easy to use, and is already adopted by many hospitals. As the CUDA technology platform is used, the stitching calculation algorithm mentioned in this paper is extremely rapid, and the calculation time needed is improved by 81.42% compared to conventional solo CPU based computation. This fully satisfies doctors' needs to obtain X-ray images in a timely manner for diagnosis. Stitching also reduces the image distortion issue effectively, and improves the overall image quality of the entire body's bone structure, and effectively improves upon doctors' understanding and diagnosis of patients' entire bone structure and health conditions.

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