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Fast Computed Tomography Image Reconstruction from 2 Dimensional projections Using Parallel Programming

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Abstract – Reconstruction of image from projection requires processing of projection data and followed by back projection. This process is computationally complex and requires considerable execution time. There are two significant types of reconstruction methods; analytical and iterative. Iterative methods are well known for their effectiveness and better performance; however they are hardly employed in real time due to computationally demanding nature. In this research work, we propose three dimensional cone- beam computed tomography (CBCT) with 2 dimensional projections. The algorithm collects slices, filters and weights the slices and back-projects the data, then a final 3D volume is created. The algorithm was implemented using various software and hardware approaches and advantage of different types of parallelism in modern processors was taken into consideration. Hardware platforms like Central Processing Unit (CPU) and a diverse system with a combination of GPU and CPU were used. On these platforms, we implement reconstruction algorithms in Parallel C and C with OpenMP extensions.

Keywords– Back projection, image reconstruction, OpenMP, GPU (Graphical Processing Unit), phantom.

1. INTRODUCTION

One of the most important non-invasive medical imaging techniques is X-ray computed tomography [1]. Clinical diagnosis of the medical image yield very important health information. X-ray CT image is the most important requirement. Computed Tomography (CT) refers to computerized x-ray imaging procedure; a x-ray narrow beam is projected on the body of the patient and rotated immediately around the body in a human sided gantry. Signals are produced from these projection and collected by the detector, computer processes these these signals through computer to obtain the cross sectional image also called as slices of the body. All the slices are collected and processed to form an image. Refer figure 1: It is the best approach that helps the doctors to detect any type of disorders, cancer using CT scanning method in finding the presence, location and size of tumor in the human body. CT is quick, non invasive, painless and accurate method to find quick internal injuries as well as bleeding. Reconstruction of the image mainly depends on the quality of reconstruction algorithm. The current algorithms can be roughly divided into analytical reconstruction algorithm and iterative reconstruction algorithm. Iterative reconstruction algorithm suffers from poor convergence speed and heavy calculations burden and other drawbacks. The most frequently used technique from histories is the Filtered back projection (FBP) algorithm.

In this paper, the main objective is to accelerate the reconstruction of 3D CT images from 2D projection. There are several techniques to accelerate the image reconstruction among them, the embedded chip and GPU are commodity chips designed to drive faster multimedia applications such as computer-aided design (CAD) systems and gaming. However, a low cost solution was provided by these chips to solve compute-intensive problems not only in medical area but also in multimedia field. In this paper, we discuss how the concept behind is to simulate the x-ray emission in CT scan by lines which cross the image that we want to reconstruct.

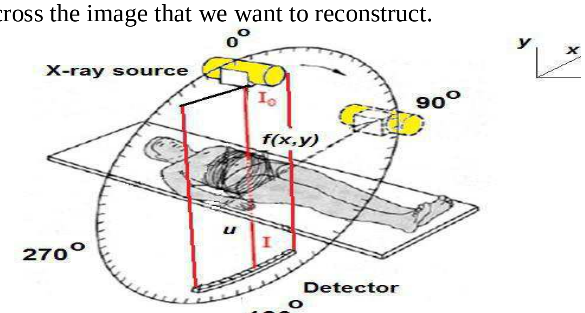

Figure 1: Computed tomography(CT)

A dozen of self sufficient and simple processors are used to characterize the GPUs, each with several execution units, a high computational throughput for data-parallel algorithm was supported [1]. GPU, a kernel is the central data parallel function that is applied to block of data. A device scheduler was used to spawn the trillion the threads that execute the kernel function. It helps in partitioning them from the GPUs actual execution capabilities. These threads are organized or arranged in chunk that may contain up to 512 threads in a 1d, 2d, or 3d layout (currently fixed for all blocks). Chunks themselves are arrayed in 1d, 2d, or 3d layouts within the one grid that occupies the GPU. Every single thread is aware of its "location" in its parent block, and that block's location in the grid, and through these location indexes (and dimensions for blocks and the grid), a thread can calculate which chunk of data it is to operate on. Shared memory is used for the threads within the blocks to communicate and synchronization barriers, so a block must run on a single "processor."

2. RELATED WORK

Image reconstruction is a rapidly evolving industry. It is necessary to take a look at what has been done in this field during the last years.

1) The first approach was categories as improved algorithm by Fredrick Anderson et.al [2], algorithm used here is the Fast FB algorithm that operates on convolutional operators. Here inbuilt functions like the ATREAv1.5, NiftyRak v2.0.1, Matlab v2014b are used for easy and fast image reconstruction.
2) The second paper was also categorized under improved algorithm by Katsevich et.al [3], a standard medical imaging modality like spiral CT (Fast extract FBP).
3) This paper is also categorized under improved algorithm by Husdon et.al [4], implementation was done using ordered subset method also known as Ordered subsets EM (OS-EM) provides a restoration imposing a natural positivity condition and with close links to the EM algorithm. Introduction and assess performance of the OS-EM algorithm and to regularize form. The main goal or aim is to show the acceleration of convergence accomplish with OS.
4) "A parallel implementation of 3-d CT image reconstruction on hyper cube multiprocessor" by C. M. Chen and *S.-Y. Lee and* Z. H. Cho [5], this paper is categorized under parallel computing. Here a message passing multiprocessor technique was implemented for faster conventional algorithm and parallelism.
5) "Use of Transputers in a 3D Positron Emission Tomograph" by M. Stella Atkins et.al [6] also categorized under parallel computing. A parallel 3-D image reconstruction algorithm on the network of transputers using both data-partitioning approaches was implemented to obtain the image. 3-D image reconstruction was achieved within 10 minutes using 200 nodes which can be improved.
6) "RAM-based neural network for image reconstruction in process tomography" by P.M. Duggan and T.A. York .Proposed method was RAM-based neural network (Pattern recognition).These include drastically reduced training times- requiring single exposure of the training set, fast recall, incremental learning ability and affinity to hardware implementation.The RAM - based network investigated here have advantages over the more traditional types, such as the multi-layer perceptron algorithm known as back propagation.
7) "Maximum Likelihood SPECT in ClinicalComputation Times Using Mesh-Connected Parallel Computers" by A. W. McCarthy and M.I. Miller. Proposed method was fully parallel implementation of the maximum-likelihood method for single-photon emission computed tomography. Emphasizing that the DAP-610 used here is now fairly old technology, with the newer machines running at twice the speed and containing additional hardware for floating point multiply assist.

3. METHODS IMPLEMENTED FOR PARALLEL PROCESSING OF IMAGE RECONSTRUCTION

As mentioned in the introduction there are two main algorithms implemented for image processing.

3.1 Analytical Reconstruction

The filtered back projection method is predominantly used with most commercial x-rays CT or PET CT scanners. With FBP the projection data are first filtered and then the filtered data is linearly smeared back along ray paths to form image pixels. For example, in the parallel beam geometry the relationship between the projection data and the object are described as follows,

$$P(\theta,t) = \int f(x,y)dl,$$

Where $P(\theta,t)$ is the projection data measured at an projection angle θ, and t the detector position in the beam.

3.2 Iterative Reconstruction

The iterative reconstruction methods include statistical reconstruction(SR) algorithms and algebraic reconstruction techniques, but they all compute the final image iteratively through the same top level loop.There are many IR algorithms available . Representative algorithm are the maximum likelihood (ML) expectation maximization (EM) formula, the simultaneous algebraic reconstruction technique and the convex algorithm. With ML-EM the image is obtained iteratively as an optimal estimate that maximizes the likelihood of the detection of the actual measured photons based on the statistical model of the imaging system. The EM model can be deterministically interpreted as the process of minimizing the I-divergence between the estimated and measured projection data in the non negative space. The SART algorithm minimizes the mean square error between the estimated and measured projection in the real space. The convex algorithm is the statistical reconstruction algorithm for the transmission CT, which also aims at maximizing the Poisson likelihood. The IR algorithm is superior to the analytical methods in the terms of image quality (contrast and resolution) with noisy and or incomplete projections.

In order to accelerate the reconstruction of images, parallel processing plays a vital role.

The approach is to parallelize the computation. The most time consuming part in the reconstruction process is the back projection in FBP, and both forward projection and backward projection. Various parallelization schemes have been proposed to distribute the workload of back projection and forward projection among the parallel computing units.

3.3 Radon Transform

The Radon transform is the projection of the image intensity along a radial line oriented at a specific angle. If theta is a scalar, R is a column vector containing the Radon transform for theta degrees. If theta is a vector, R is a matrix in which each column is the Radon transform for one of the angles in theta.

$$R=radon(I,\theta)$$
$$[R,xp] = radon(...)$$

R = radon (I, θ) returns the Radon transform R of the intensity image I for the angle theta degrees.
[R,xp] = radon (...) returns a vector xp containing the radial coordinates corresponding to each row of R. I=iradon(R,θ)
I=iradon(P,theta,interp,filter,frequency_scaling,output_size)
[I,H] = iradon(...)
iradon uses the filtered back-projection algorithm to perform the inverse Radon transform. The filter is designed directly in the frequency domain and then multiplied by the FFT of the projections. The projections are zero-padded to a power of 2 before filtering to prevent spatial domain aliasing and to speed up the FFT.
I = iradon(R, theta) reconstructs the image I from projection data in the two-dimensional array R. The columns of R are parallel beam projection data.

I= iradon(P, θ, interp, filter, frequency_scaling, output_size) specifies parameters to use in the inverse Radon transform. You can specify any combination of the last four arguments. iradon uses default values for any of these arguments that you omit.

3.4 Filtered Back Projection

After numerous back projections,which results in rendering the original input where major portion goes in nullified ,except the intensities at the position of the original spot.This can be demonstrated by taking a single point in the cross section of the biomedical data where an random projection is sum of a large number of suck kind of points,and since the system restrains to be linear.Thus we can enunciate that the same operation on numerous number of random projections will be resulting the complete cross -section

$$g(r, \quad) \quad [\ f(\ ,\ )e^{2} \quad d\ ]|\ \ |e^{i\,2} \quad \cos(\quad) d\ d$$
0

The mathematics of the image reconstruction process, can be expressed in the above equation, where the terms have been grouped to reflect the “filtered-back-projection” approach.Where $g(r,\ )$ is reconstructed image , $f(\ ,\ )$ are the original projections, $f(\ ,\ )e^{2} \quad d\ ]|\ \ |$ FT of projections at Each angle multiplied by

$$[\ f(\ ,\ )e^{2} \quad d\ ]|\ \ |e^{i\,2} \quad \cos(\quad)$$

ρ
| |, is the inverse Fourier transformed applied for reconstruction,

$$[\ f(\ ,\ )e^{2} \quad d\ ]|\ \ |e^{i\,2} \quad \cos(\quad) d\ d$$
0 back project at each angle Φ.
.

4. RESULTS AND DISSCUSION

For the proposed work phantom images are chosen. Phantom could be a ideal test image.Since it is the synthetic image model of the human head within the development and testing of image reconstruction algorithms and approaches.

4.1 Experiments

We substantiate the implementation of the FDK formula on various forms of architectures: Sequential implementation (CPU) and Parallel implementation a mix of (CPU and GPU). Details of the various hardware is summarized in table I.

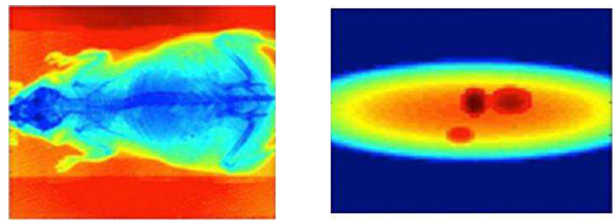

Figure 2: Mouse Scan and phantom Image.

TABLE 1: PERFORMANCE ANALYSIS OF VARIED IMPLEMENTATIONS FOR PHANTOM (IN SECS)

Dataset	Approach	Backprojection time	Total time	Speedup over MATLAB	Speedup over C
Phantom	MATLAB	51.06	51.11	--	--
Phantom	C	3.93	3.95	12.94	--
Phantom	C+OpenMP	0.85	0.89	57.43	4.44

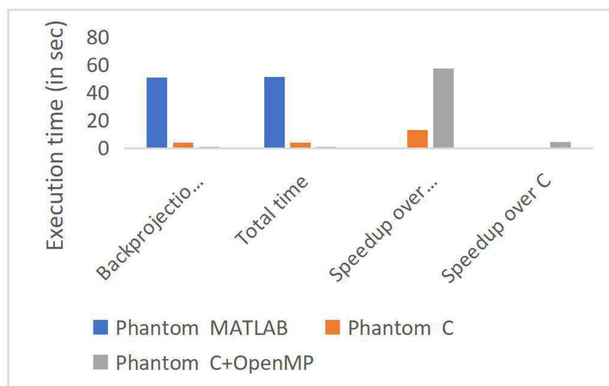

Fig 2 Runtimes of different implementations applied to phantom data

TABLE II. PERFORMANCE ANALYSIS ON VARIED IMPLEMENTATIONS FOR MOUSE SCAN (IN SECONDS)

Dataset	Approach	Backprojection time	Total time	Speedup over MATLAB	Speedup over C
Mouse Scan	MATLAB	33760.4	33777.33	--	--
Mouse Scan	C	22506.49	22513.9	1.5	--
Mouse Scan	C+OpenMP	18451.77	18462.6	1.83	3.29

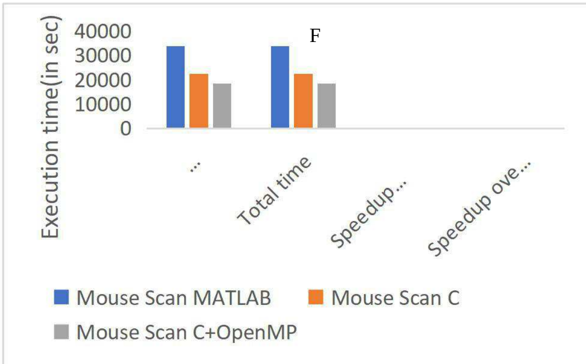

Fig 3 Runtimes of different implementations applied to mouse scan Data

TABLE III. COMPARISON ANALYSIS BETWEEN SEQUENTIAL AND PARALLEL PROGRAMMING

	Sequential Programming		**Parallel Programming**		Xun Jia et.al,2010	Liubov A.F et.al,2104
Number of Projections	**36**	**360**	**36**	**360**	20-40 X-Ray Projections	400 projections ,0-360,ia=0.9 degrees
Event	**Execution Time**	**Execution Time**	**Execution Time**	**Execution Time**	Digital NCAT phantom image	Medical CT images
Generating 1-D Projections	0.205267 sec	2.05267 sec	2.31686 milli sec	231.686 milli sec	70-130 sec	5.3 sec
Back Projection	0.213599 sec	2.13599 sec	3.02560 milli sec	302.560 milli sec		
Total Time	0.214552 sec	2.14552 sec	6.89597 milli sec	689.597 milli sec		
					GPU based fast cone beam algorithm	Parallel CT image reconstruction based on GPU

Result computed from matlab implementation on CPU; gives total elapsed time for computation is 2.56 sec which is higher than the GPU computation, Therefore, the implementation using OpenMP and C on GPU gives better results compared to MATLAB implementation CPU.

TABLE IV. COMPUTATIONAL COMPARISON BETWEEN C AND OPEN MP

Comparison between CPU and GPU Computational Time		
	C	***OPENMP***
Weighing Projections	**0.0063 sec**	**1.486 ms**
Filtering Projections	**0.077021 sec**	**69.388 ms**
Reconstruction of image	**2.05267 sec**	**231.686 ms**
Total Processing Time	**2.13599 sec**	**302.560 ms**
Total Execution Time	**2.14552 sec**	**689.597 ms**

Parameters obtained as output in execution of back projection of phantom head model in C and OpenMP are as follows:
-Weighting projections are performed using Feldkamp Weight algorithm and Ramp Arc function.
-Filtering projections applying Ramp filter function and Feldkamp-Davis-Kress fan filter function.
-Reconstructing the image.
-Writing image to output file .
are the major time segment parameters in complete execution of the reconstruction process.

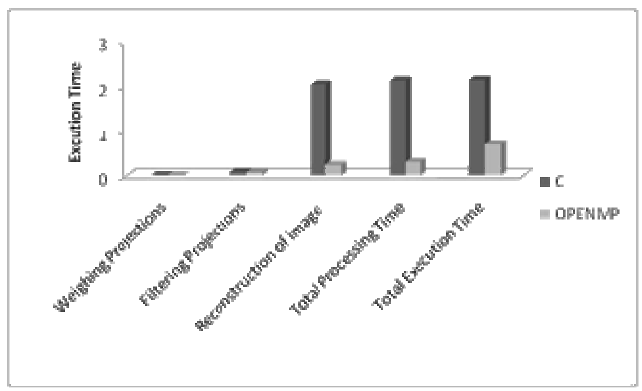

Fig 4 .Run time analysis between OpenMP and C.

5. CONCLUSION AND FUTURE WORK

This study presents several ways to speed up the FBP algorithm on different target architectures: general purpose CPU (muti-core), GPU. The algorithm exploits the computational capability of different platforms. As per the main objective of this project reconstruction of the 3-D images from 2-D projections using GPUs is to be accelerated. Therefore the implemented methods using GPUs seems to generally outperform the present time taken to generate the results.Parallel programming yields improved speed-up factor as compared sequential programming only when number of 2D projections are 360 or more.

Future scope may be Parallel computing has several benefits, as it is reliable,robust, low-cost, and also with performance potency which is economical. From super-computers to computer clusters; from a neighborhood cluster to an overseas cluster server, over the decades have evolved the ongoing trend .Thus high performance computing technology have evolved into this trend where completely different parallel programming platforms shall be additional explored to analyse the performance and benefits .

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