Volume 8, No. 5, May-June 2017
ISSN No. 0976-5697
International Journal of Advanced Research in Computer Science
RESEARCH PAPER
Available Online at www.ijarcs.info

Performance Improvement of Basic Medical Image Processing Operations on Multicore Architecture using Open MP

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Abstract: The growing trends in multicore architectures paves way for increasing the speed of a lot many medical imaging operations in real-time. Various imaging operations like restoration, registration, processing are improved in performance and accuracy by exploiting the multicore CPUs and GPUs. The aim of this paper is to study impact and influence of multicore architectures in improving the performance of medical image processing using OpenMP. It includes study and analysis of OpenMP language constructs to process the modality images like CT, MR and PET.General Terms Filtering,Average,Median,Highpass,Lowpass,parallel.

Keywords: DICOM, GPU, Multicore, Performance, Pipeline, Speed,OpenMP.

1. INTRODUCTION

X-ray was the primary imaging method in most of the radiology departments until late 90s, as explained by Rowlands [1]. The difference in the pricing of scans by different modalities as getting doubled for Computed Tomography (CT) and tripled for Magnetic Resonance (MR), according to the report published by Medical News Today [2] plays a key role in Medical Imaging market. With growing number of image acquisition techniques and size of the captured images, it is very important to tap the potentials of the existing latest technologies in overcoming the bottlenecks. Due to the rapidly increasing demands on high-performance computing for more sophisticated graphics and scientific applications, commercial graphics hardware has evolved significantly from a pipeline with fixed functionalities into a programmable supercomputer [3].
The CT and MR modalities increase the number of slices and size of the image captured per second, thereby making the diagnosis more accurate from the radiology perspective. However, the need to optimize the performance of processing, storage, transfer of the images without losing vital information becomes obviously evident. In addition, security also plays an important role during storage and transfer. There are various security mandates imposed on medical imaging and transfer. One of these is that the recommended retention time for the medical records may vary between 6 and 25 years, based on various criteria [4]. There are evidences of radiologists waiting for the data for a considerable time for diagnosis and the time factor is important because the data is critical and life saving. Hence, time and quality are key factors in healthcare industry which are to be improved. To add on, the processing power of the latest multicore processors also should be tapped.

2. CONCURRENT VS PARALLEL

Until recently programming in processor (single core) was sequential. Processing and its speed were the main factor for Performance (concurrency). But in the present, multicore processors are available, which are true parallel computing hardware platform. When multiple software threads are executing concurrently, they are scheduled in an interleaved fashion on a single hardware resource. When multiple software threads of execution are running in parallel, the active threads are executing simultaneously on different hardware resources. Multiple threads may make progress together. This is referred as multi-core parallelism. Intel dual core processor is MIMD (Multiple Instruction, Multiple Data). i.e. it is capable of executing multiple instruction streams while working on different independent data. The only way for taking full advantage of the available core is, ‘Increased Concurrency’, which is the next major revolution in the computational methods [5].

3. APPLICATION OF MULTICORE IN MEDCIAL IMAGING

The following are the three main areas of medical imaging in which multicore is deployed.

- Image Processing
- Image Registration
- Image Segmentation
- Image Reconstruction
- Image Storage and Transfer

3.1 Image Registration

One of the fundamental tasks which is frequently encountered in a medical image processing application is registration [6]. The process of aligning the different frames of an image based on various features present in it is Image registration. There are two major types of registration methods. One involving anatomy of the images known as intrinsic and the other involving artificially introduced features of the image, called extrinsic [7]. Ramtin et.al describe the advantages of using GPUs when there is a need to perform more geometric calculations in image registration [8].

3.2 Image Segmentation

Image segmentation is the process of segmenting the medical images based on different density of the tissues, be it hard or soft. It plays a very important role in filtering the diseased tissues from the healthy tissues in a post processing workplace. Using the segmented regions, physicians can rapidly and accurately diagnose and treat diseases. Sanjay et.al describe about the positives of usage of multicore processors in applying segmentation to each of the organs in different processors parallel [9].

3.3 Image Reconstruction

Image reconstruction is the process of constructing a volume of the streaming frames during the process of scanning. Often the expectation is that the reconstructed image should be available exactly at the point of time, when the scan completes. This requires a lot of algorithmic calculations and correlation operations to be performed on the slices so that the image can be constructed fast.

3.4 Image Storage and Transfer

Medical image storage and transfer play a very important role in saving patient's life. It involves protocols like DICOM (Digital Imaging and COmmunication in Medicine), HL7 (Health Level 7) and HIPAA (Health Insurance Portability and Accountability Act) for transfer and regulation of medical data. In the recent past cloud technology gained momentum in storage solution but handling security issues related to patient data is still a challenge. Since the image transfer can be a life saving on emergency situation, the research world started exploring various performance improvement techniques using multicore.

4. GPU AND ITS APPLICATION IN MEDICAL IMAGING

The currently advancing multicore architectures pave way for low cost, high performance computational units [4]. The GPGPUs (General Purpose computing on graphic processing unit) available in the market provide a high computational capability that can be unleashed for various medical imaging operation. Andres et.al describe about the usage of GPU in basic image processing operations like filtering, zooming and modality specific operation like registration and reconstruction [10]. The GPU is always designed for a particular class of applications with the following characteristics [11]: (i) large computational requirements, (ii) substantial parallelism, and (iii) throughput is more important than latency. An article by Bui and Brockman [12] depicts a performance analysis of accelerated image registration using GPGPU and emphasized the demand to manage memory resources carefully to fully utilize the GPU and obtained maximum speedup CUDA (Compute Unified Device Architecture) is the most extensively used GPU programming language. For the convenience of general-purpose parallel programming on the NVIDIA GPU, the CUDA brings the C-like development environment to programmers [13].

5. OPENMP

Open MP can be better explained as a language extension that introduces parallelization constructs into the development platform. In this library, parallelization is orthogonal to the functionality. It is a heterogeneous library, even if the compiler does not recognize the OpenMP directives, the code remains functional (single-threaded). OpenMP includes constructs for parallel programming: like critical sections, atomic access, variable privatization, barriers etc. It is an industry standard supported by Intel, Microsoft, Sun, IBM, HP, etc., [14].

OpenMP constructs are compiler directives or pragmas. The focus of OpenMP is to parallelize the loops constructs. OpenMP offers an incremental approach to parallelism.

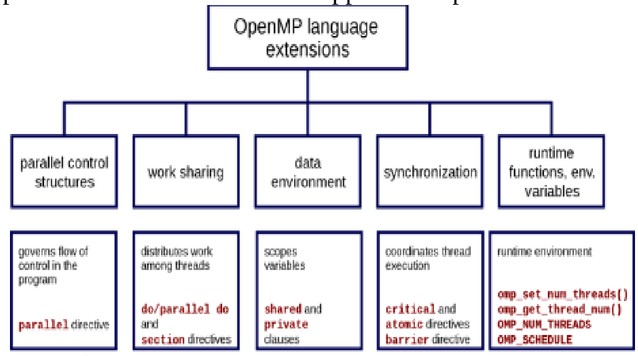


Fig.1. OpenMP Language Extensions

6. PROGRAMMING MODEL IN OPENMP

The unique feature is the Fork-join model of parallel execution. The software begins execution as a single process (master thread). In the start of parallel construct, the master thread creates team of threads and on completion of a parallel construct the threads in the team synchronize to give the final output.

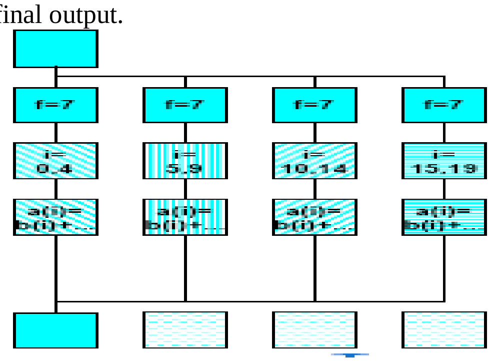


Fig.2. Fork Join model of OpenMP

7. MEDICAL IMAGE PROCESSING OPERATIONS

Medical Image processing poses a tough challenge when compared to the images taken using digital camera because of the presence of low signal to noise ratio [15]. The presence of low contrast [16],[17] in the different anatomies in modalities like Angiography images poses more difficulty for proceesing of the images.

This study involved the optimization of the following basic image processing operations on various modality medical images of different sizes, in a basic medical image processing C++ application.

- Averaging Filter
- High Pass Filter
- Low Pass Filter
- Median Filter
- Sober Gradient Horizontal (top to Bottom)
- Prewitt Horizontal
- Histogram Equalization

All our experiments were performed with intei i7 processor with quad core. Since all the above operations involve in processing the images in pixel level, OpenMP is selected due to its fork-join capability. These operations along with OpenMP optimization show that there is at least a 30% improvement with minimal optimizations when OpenMP is used for image processing. This performance improvement can increase to 70% in some cases.

8. IMPACT OF USING OPENMP

The advantage of using OpenMP in the C++ application is that pixel level processing of images are distributed to all cores and the output is consolidated by the library. The OpenMP constructs helps to optimize the program of loop processing to a greater extent.In some cases we had to restructure the code so that the constructs can be used effectively.

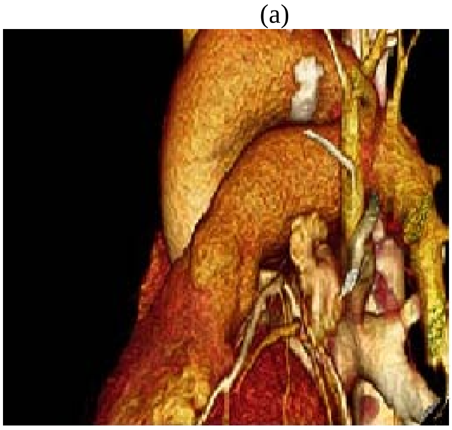
9. PERFORMANCE OF MEDICAL IMAGE PROCESSING OPERATIONS USING OPENMP

We implemented a C++ application with basic image processing filter operations to carry out the analysis.Various modalities like CT,MR,PET images were delivered to the application and the results observed.

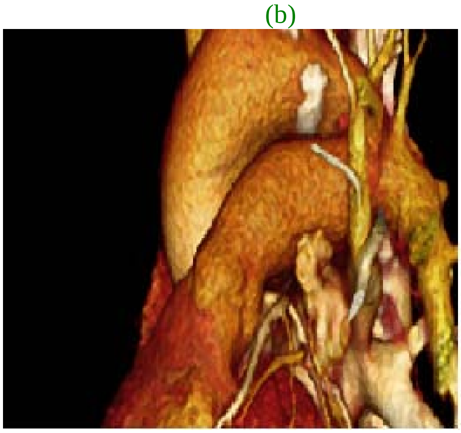
9.1 Median Filter

This operation applies 3×3 median filter on the medical image. The algorithm involves considering the pixels of 3×3 matrix, sorting the pixels and determining the center pixel to find the median. The analysis on various sizes of medical images shows a clear improvement of performance.

(a)



(b)



(c)

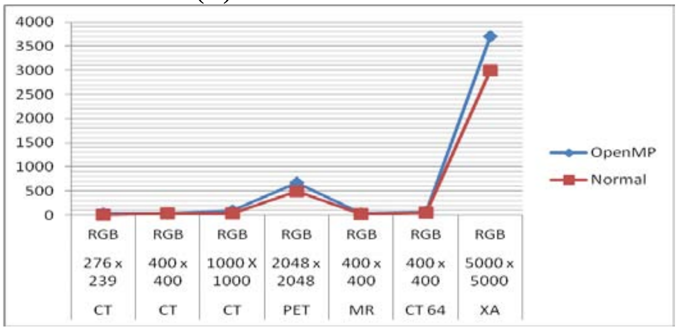


Fig.3. CT image with Median Filter Applied (a) Original CT Image (b) Output after appling median filter (c) graph showing results in ms

This filter generally causes a blur effect on the image reducing noise. The figure 3 shows that the median filter being applied on a cardiac CT image which is of size 400×400.. The CT image samples with varying sizes showed performance improvement varying from 30-70%.The table 1 shows the performance improvement achieved by using OpenMP to parallelize the color planes and calculate the median.

Table 1**: Performance of Median Filter using OpenMP (in milliseconds)**

Modality	**Image Size in pixels**	***Image Type***	***Processing Time (in Milliseconds)***	
			Normal	***OpenMP***
CT	276 x 239	RGB	38	15
CT	400 x 400	RGB	53	38
CT	1000 X 1000	RGB	157	63
PET	2048 x 2048	RGB	700	588
MR	400 x 400	RGB	37	28
CT 64	400 x 400	RGB	79	63
XA	5000 x 5000	RGB	3800	3200

9.2 Averaging Filter

(a)

(b)

(c)

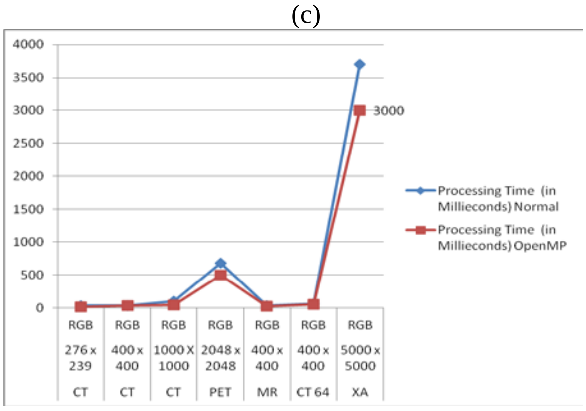


Fig.4. CT image with Averaging Filter Applied (a) Original Image (b) Output after appling Averging filter (c) graph showing results in ms

The algorithm of averaging filter involves finding the average of nearby pixels to calculate the target pixel value.This filter blurs the image by reducing the noise. The figure shows the effect of average filer in a CT image.The table 2 shows the performance improvement achieved by using OpenMP to perform averaging filter.

Table 2: Performance Values Of Averaging Filter in milliseconds

Modality	**Size of the Image in pixel**	***Image Type***	***Processing Time (in Millieconds)***	
			Normal	***OpenMP***
CT	276 x 239	RGB	30	12
CT	400 x 400	RGB	38	30
CT	1000 X 1000	RGB	100	40
PET	2048 x 2048	RGB	680	496
MR	400 x 400	RGB	35	20
CT 64	400 x 400	RGB	60	55
XA	5000 x 5000	RGB	3700	3000

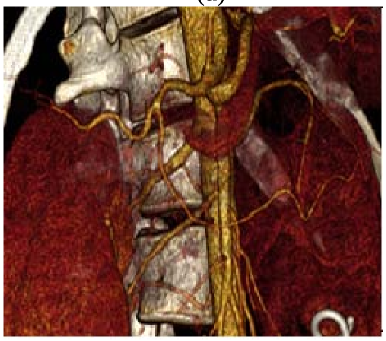
9.3 High Pass Filter

The high pass filter allows only high frequencies and blocks low to mid. This filter produces a performance improvement from 30% to 50% on various modalities when OpenMp is used for optimization. The table 3 shows the values obtained by implementing high pass filter using OpenMP.

Table 3: Performance Values Of High pass Filter in milliseconds when using OpenMP

Modality	**Size of the Image in pixel**	***ImageType***	***Processing Time (in milliseconds)***	
			Normal	***Open MP***
CT	1000 x 1000	RGB	96	53
MR	800 x 800	RGB	89	35
CT	1000 X 1000	RGB	157	63
CT	400 x 400	RGB	38	15
MR	400 x 400	RGB	37	13
CT 64	400 x 400	RGB	79	50
XA	5000 x 5000	RGB	4000	1109

(a)



(b)

(c)

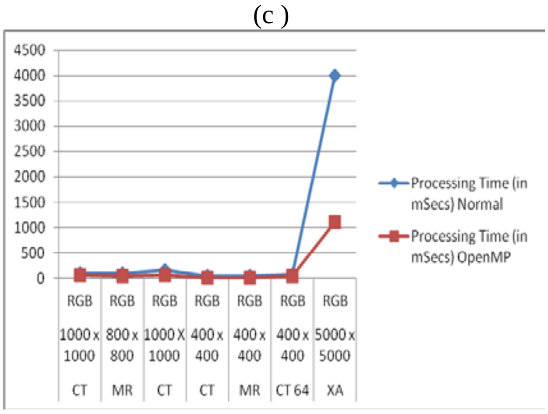


Fig. 5. PET image with Highpass Filter Applied (a) Original Image (b) Output after appling Highpass filter (c) graph showing results in ms

The figure 5(a-b) shows the high pass filter applied on a cardiac CT.

10. LOW PASS FILTER

The low pass filter used in this operation allows only slowly changing frequencies to pass thus reducing the noise of the image to a considerable extent. This filter produces a performance improvement of 40% to 70% when implemented using OpenMP.

The observation shows that the performance has improved to 70% for images of higher sizes.

(a)

(b)

(c)

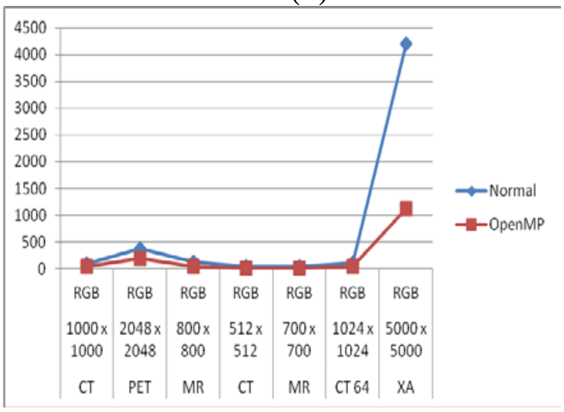


Fig. 6. CT image with Lowpass Filter Applied (a) Original Image (b) Output after appling Lowpass filter (c) graph showing results in ms

The following table(Table 4) shows the performance of a low pass filter in OpenMP.

Table 4: **Performance Values Of Low pass Filter in milliseconds when using OpenMP**

Modality	**Size of the Image in pixel**	***ImageType***	***Processing Time (in milliseconds)***	
			Normal	***Open MP***
CT	1000 x 1000	RGB	88	37
PET	2048 x 2048	RGB	380	197
MR	800 x 800	RGB	120	35
CT	512 x 512	RGB	40	16
MR	700 x 700	RGB	37	15
CT 64	1024 x 1024	RGB	102	38
XA	5000 x 5000	RGB	4200	1116

11. CONCLUSION

In this study, we have considered a medical imaging application with basic filtering operations and identified its challenges in adapting it with OpenMP. We also explored the different parallelization and optimization techniques that can be leveraged using OpenMP for a medical imaging processing application. The results proved that OpenMP can provide a minimum of 30% to a maximum of 70% performance improvement for CT,MR and PET images in DICOM format .Additionally when the size of images increases ,the improvement in performance also increases with OpenMP.

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