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FPGA Accelerated PET Image Reconstruction

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Abstract - In the existing PET system Image acquisition and image reconstruction are performed separately using separate systems for it. Here, Image acquisition is done first and raw data is captured which will be stored in memory. Then image reconstruction system makes use of the data stored in the memory to reconstruct the image. But this process is time consuming and acquires more space.
Analytical reconstruction and Iterative reconstruction are two widely used Algorithms for Image reconstruction of Tomography studies. Since these algorithms are implemented and run on CPU's and GPU's they are consuming time for its execution. It has been proven that FPGA's provide much faster execution with great amount of optimization because of its parallel computing ability. Here, in this paper an attempt is made to realize these algorithms on FPGA using Intel SDK for Open CL in integration with Altera Offline Compiler.

The results prove that implementation of Reconstruction Algorithm on FPGA using Open Computing Language along with Altera Offline compiler has given great reduction in execution time when compared to execution using CPU and GPU. Optimization is also achieved in the course of logic compilation and execution.

Keywords— **Accelerated FPGA, Intel SDK for Open CL, Analytical Image Reconstruction, PET/CT.**

1. INTRODUCTION

Positron emission tomography–Computed tomography (PET/CT) is an imaging-technique in which we use a single device that combines both PET and a CT devices in a single gantry structure and images captured from these two devices are combined and a single better quality image will be formed. It makes use of both the devices to get the better result so that diagnosis will be easier.

Tomographic reconstruction is a kind of multidimensional imaging. The problem is to yield a combined image reconstruction using a definite number of projections. The CT cross-sectional images taken from patients are optained in non-invasive fasion.

Analytical reconstruction and Iterative reconstruction are two most used reconstruction mechanisms in Tomographic imaging. Since, Multi dimensional matrix are to be manipulated by the processor, it is time consuming. Because, no optimization will be applied and multiple process will be carried over by the basic processor.

It has been seen that, single core CPU are being replaced by multicore CPU. Further introduction of GPU increased the speed of execusion. More number of tasks can be carried out at the same time using these high speed processors. As the technology evolved, introduction of FPGA increased the speed of execution better than multicore CPU's and GPU's which has resulted in large number of processes getting executed in short duration of time.

Intel SDK for Open CL, is a software development kit used for programming FPGA's with greater ease and efficiency. This enables the programmers to design and verify their programs much more faster and with much more optimization when compared with conventional methods of FPGA programming using Hardware Descriptive languages like Verilog and VHDL.

Open computing language have proven to be one of the best optimized computing language for field programming gate array. The Altera Offline Compiler used in integration with Open CL keeps track of program and provides optimization in programming logic and syntax that can be achievable.
The process of data accusation, data storage and image reconstruction is time consuming. Since all are being done one after the other using CPU and GPU. The approach is to realize these techniques on a much faster and optimized approach on a FPGA using Intel SDK for Open CL in integration with Altera Offline Compiler.

2. METHODOLOGY

A. CT(Computed tomography)

A CT scan,known as X-ray pictorial representation computerized tomography CT computerized axial-tomography.(X-ray CT) or computerised axial tomography scan(CAT-scan) makes use of computer processed mixtures of the many Xray pictures taken from tota1ly different angles to provide crosssectional (tomographic) pictures (virtual -slices) of specific areas of a scanned object, permitting the user to ascertain within the item while not cutting.

Digital - geometry process is employed to get a 3-dimensional image of the interior parts of the item from an oversized series of 2-dimensional picture taking pictures taken around one axis of rotation. Medical-imaging is that the most application of X-ray CT. Its crosssectional pictures ar used for diagnostic and therapeutic functions in varied disciplines of medicine.

PET (Positron Emission Tomography)

Positron emission Tomograph (PET) is used in nuclear-medicine, useful imaging technique that produces a 3-dimensional image of usefull-processes within the body. The systems detect pair of gamma-rays emitted in-directly by a positron emitting radionuclide (tracer),that is introduced onto the body of a biologically-active molecule. Threedimensional pictures of tracer -concentration at intervals the body square measure then created by laptop analysis

If fluorodeoxyglucose (FDG) is the biologically active molecule chosen for PET, Associate in Nursing analogue of aldohexose, the concentrations of tracer imaged can indicate tissue metabolic-activity because it corresponds to the regional aldohexose uptake. Using this tracer to explore the chance of cancer-metastasis (that is, spreading to different parts) is that the most typical sort of PET scan in customary treatment (90% of the current scans).

PET/CT

Positron emission tomography/computed tomography is defined as medical-imaging technique ,which uses a device consisting of a single gantry, both a positron emission tomography (PET) scanner and an X-ray computed tomography (CT) scanner, which results in images taking during both devices operation are to be captured sequentially, and then they are combined to a single image. So, functional imaging obtained using PET, which shows the spatial distribution of metabolic act scanners. 2 and 3 dimensional image reconstruction of a common software and control system will be used as a function.
Other obstacles for the enhanced use of PET/CT will be the difficulty of production cost and shifting of the radiopharmaceuticals required for PET-imaging, which are short-lived (for example, halflife of radioactive fluorine -18 used in trace of glucose-metabolism uses fluoro deoxy glucose, (FDG) is 2 hours only). Its production is very expensive, which requires cyclotron and a separate production line for the radio-pharmaceuticals.

Open CL Dessign

Field-programmable gate arrays (FPGAs) are integrated circuits that we can configure again and again to carry outinfinite number of functions. FPGA is made up of several small computational units. Custom data-paths and designs can be built directly into the fabric by programming the compute units present in it. Data flow is programmed directly into the FPGA architecture.

Open Computing Language is a framework from Altera, that is used for writing programs which will be executed across heterogeneous platforms. They consist for examples of CPUs, GPUs, DSPs and FPGAs. OpenCL specifies a programming language (based on C99) for programming, these devices and application programming interfaces (APIs), to control the platform which are desired to work and execute programs on the compute devices for reduced time consumption. OpenCL will provide a standard interface for parallel-computing using, task-based and data-based parallelism techniques.

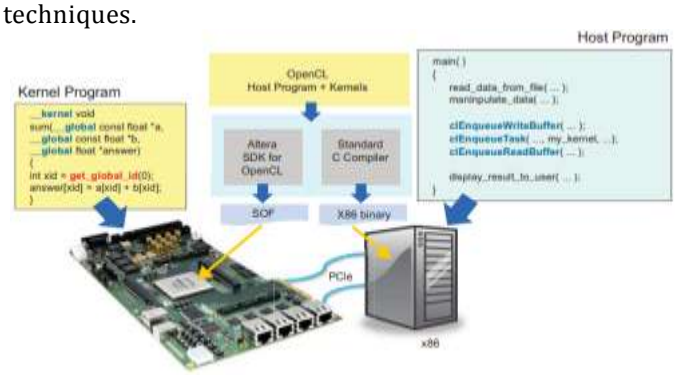


Fig1. Open CL Overview

Other than kernel-pipeline, Altera's OpenCL compiler creates an interfacebetween internal and external memory. The store unit and load unit for each pipeline unit are connected to external-memory using a global interconnect structure, that will arbitrate many request to group of DDR(Dual Data Rate)DIMMs. Same way, Open CL local memory accesses are connected using a different interconnect-structure to on chip M9K RAMs. These specialized interconnect-structures, are designed and structured to guarantee high frequency of operation, effective and efficient-organization of memory requests.

3. TECHNIQUES

A. Image Reconstruction

Positron emission tomography(PET)scanners collect measurmentsof patients in-vivo radiotracer distributions.These measurments are ,reconstructed into crossectional-images.Tomographic image reconstructions form images of functional informations in nuclear-medicine application along with that, same principles will be applied to other applications such as Xray computed-tomography. The reconstrction methods are analytic and iterative approachs. Analytic-reconstruction methods, gives us direct mathematical-solution for formation of the images. Iterative-method is basically on precise details of the imaging processesresulting to a more complex mathematical-solution which takesmore steps to result in an image.

B. Back Projection

Back-projection is an important step in image reconstruction, which is an adjoint to forward projection process, that gives projection of the object. Back-projection along a fixed angle is shown in the figure. Conceptually, back projection is described as giving and placing, a value of angle back onto an image array along the consequent Line of Response, the best that can be done is place constant

value in all elements along the LOR, since the knowledge of where the values came from are lost in the projection-step.

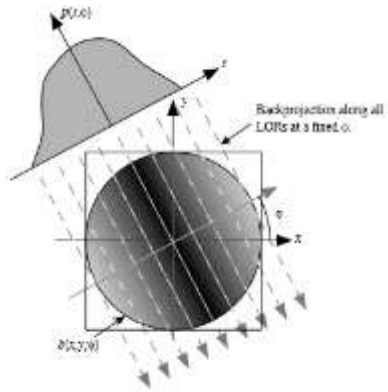


Fig2: Backprojection

We can assume that, straight back projection of all the co1lected projection values should return a image, but this does not happen due to the oversampling that occurs while performing Fourier transform. That is, each projection completes in 1 slice of the Fourier space which results in over sampling at the countermand less sampling towards the edges. Another approache of understanding over sampling in space-domain is with the forward projection of a point source. If we back-project the point-source projections, it forms blurred image, since the projections will be summed back to the Line of Response from which they came. The over sampling should be reweighted or filtered, in order toget same contribution throughout field of view.

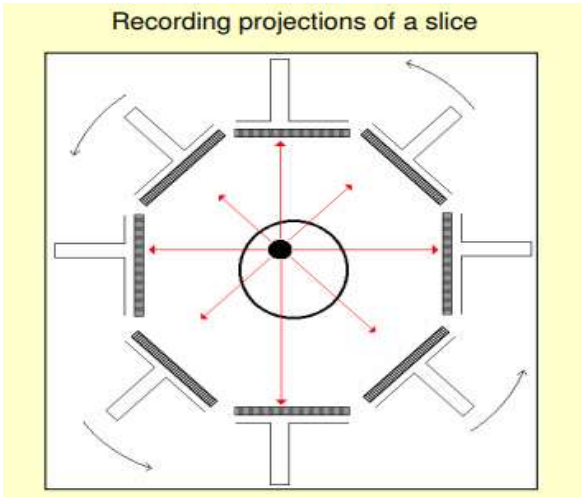


Figure: Emission and Capturing of X-Ray

Tomography is carried out in two steps:

- 1st step:Data-acquisition(record of projections): Result will be set of angular-projections. The collection of projections resulting from a single-slice is called “sonogram”.
- 2nd step:Image-reconstruction from projections:

There are two types of reconstruction-methods: analytic-reconstruction (e.g.FBP:filtered-back-projection)and iterative-reconstruction (e.g.ART:algebraic-reconstruction-techniques).

C. Analytical Reconstruction

Analytic-reconstruction methods (e.g., the filtered backprojection algorithm) are efficient,(fast) and elegant, but they will not be able to handle complicated factors like scatter. Filtered back projection is utilized for reconstructions in x-ray CT and for most SPECT and PET reconstructions.

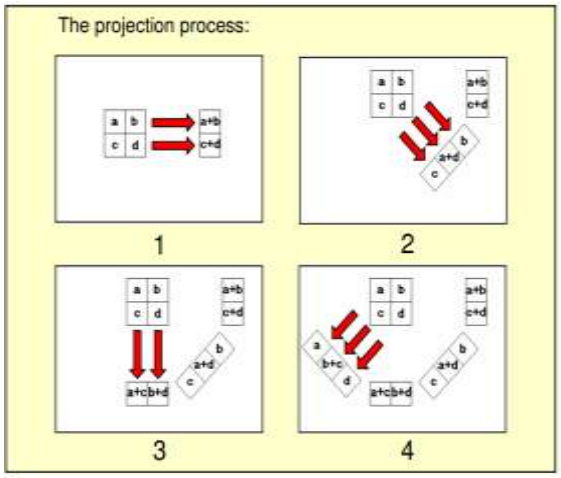


Fig. Projection of X-Ray in 4 Different Directions.

D. Iterative Reconstruction

Iterative-reconstruction algorithm, on the other side, are less efficient but more of versatile.Efficient(that is - fast)iterative algorithms are presently in development-stage. Along with progress are done in computer memory and speed, iterative reconstruction algorithm are used in most applications of SPECT, PET and will enable us to do quantitative reconstructions.

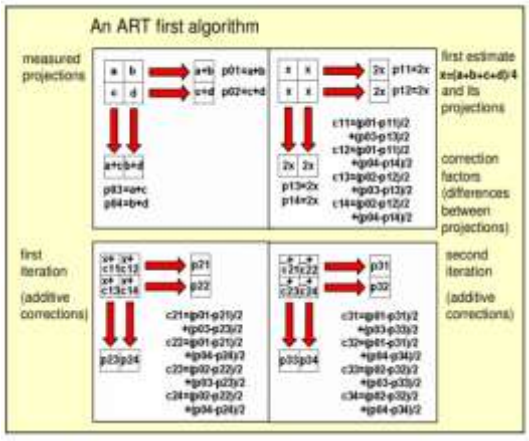


Fig Algebraic Reconstruction

The principle of this iterative-algorithm is, have a solution (that is to reconstruction of an image that is taken from a tomographic-projections) by conducting successive-estimations. The current estimate projections are compared to the measured-projections. The resulting comparison is used to change the current estimate, thereby it creates a new estimate.

The algorithm differs in the way they are estimated and measured projections are compared with each other and what type of corrections are being applied to the current-estimation. The process is started by arbitrarly creating the 1st estimation-for example, an uniform-image taken. Corrections are carried away either as multiplication by quotients or as addition of differences in betwen estimated and measured projections we have.

4. RESULTS

A. Initial Configuration

In order to program and execute programs in Open CL using Visual Studio, additional directives and libraries has to be included and linked to the program which is being executed.

Intel SDK for Open CL has several C/C++ Additional Directives which are required to run Open CL program, it includes files which are to needed in the flow of the program for execution, and also includes files which are mandatory to create and pass variables between the main program and the FPGA using Context. The figure below shows the Intel SDK for Open CL Additional Directives for C/C++ used in the project.

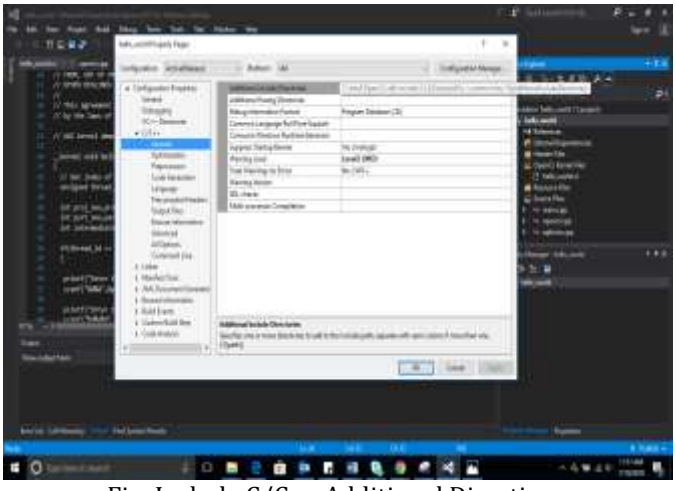


Fig: Include C/C++ Additional Directives

In addition to C/C++ directives included, several other inbuild Libraries are to be added which provides the programmer to use many inbuilt functions and keywords
.
Linker is used to add Libraries from Intel SDK for Open CL. Libraries will be used to utilize features such as Context and several other inbuilt functions to it. Below figure shows the Libraries included using Linker.

B. Command Prompt Commands

- Initialize the Open CL Batch File
- Setting up the Target Board
- Configuring Paths from Quartus to Open CL
- Altera Offline Compiler(aoc) is run

Aoc-list-board command, gives list of board configurable with the system and those boards which are connected and configured already. Required board will be selected.

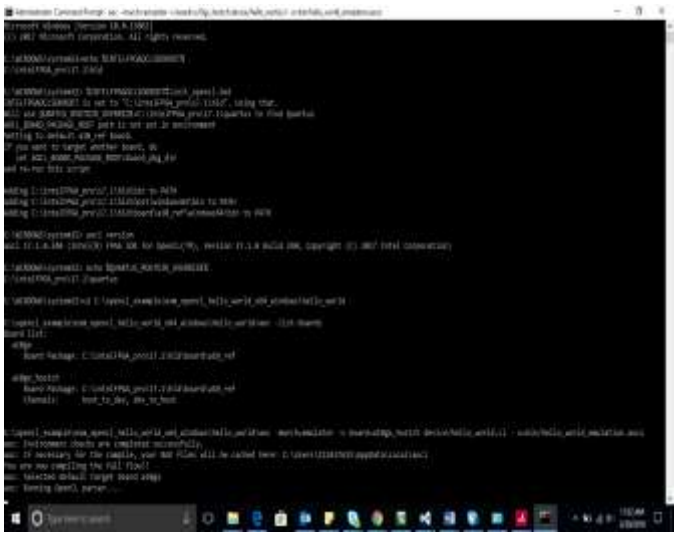
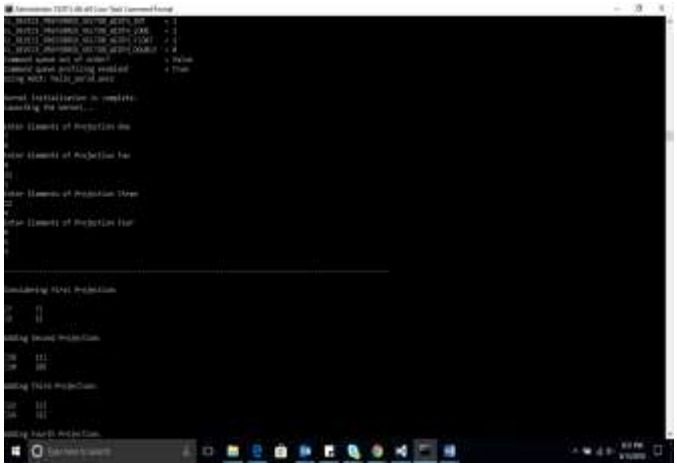


Figure: Initial Configuration

C. Analytical Reconstruction

Analytical Reconstruction takes input for Four different projections,
Reconstructed output is given in every step. Considering every projection separately, output is generated.



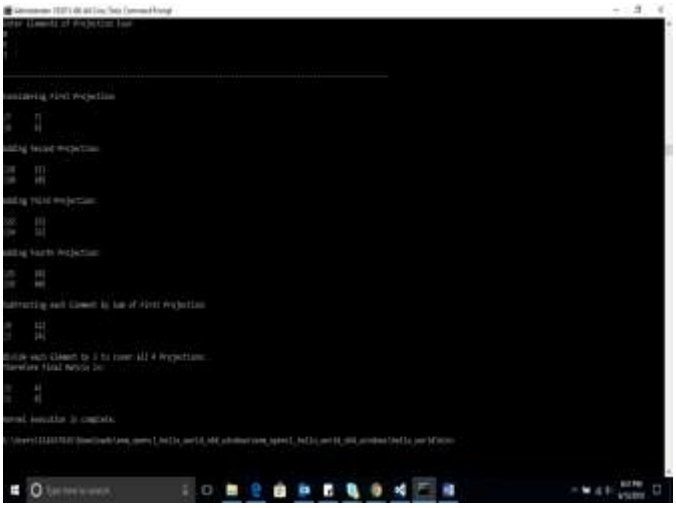


Fig. Output for Analytical Reconstrcution

Conclusions

Intel SDK for Open CL is used to execute several Algorithms and programs. Context is created to communicate with the FPGA. That is, for establishing Command flow and communication between Host program and Kernel program.

The Application is tested on several basic algorithms such as sending commands to print any statement, perform matrix multiplication and few other cases.

Host program is successful in sending set of instructions and commands to Emulated FPGA and execute the Algorithm intended. Reduction in execution time is seen, which will result in faster execution of intended Image Reconstruction Algorithm.

As step of Future work more complex algorithms with high execution time will be implemented, those algorithms which have real time execution issue with high time consumption will be implemented using Open CL, which will significantly reduce the time of execution.

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