Development of Flaw Detection Techniques in Non Destructive Testing using GPU

Atharv Bhaskar[a] Shekhar Sharma[a] Rajiv Jain[b]*

[a] Shri G.S. Institute of Technology and Science, Indore, Madhya Pradesh, India

[b]Laser Electronics Division, Raja Ramanna Centre for Advanced Technology, Indore, Madhya Pradesh, India

**Email: rajiv@rrcat.gov.in*

Abstract -**This paper proposes development of flaw detection setup for Non Destructive Testing (NDT) using Ultrasonic testing employing Graphic Processing Unit (GPU). It aims for the rapid calculation of depth of flaw and flaw location. The echo signals arises due to flaw or material discontinuities are received back by the detector. This signal contains important information of size and location of defect. This is can be processed by the various signal processing techniques to understand defect such as Short Time Fourier Transform (STFT), Wavelet Transform, Hilbert Huang Transform (HHT), Total Focusing Method (TFM) etc. The present technique uses parallelization of Empirical Mode Decomposition (EMD)[2], which is an essential as well as key part in Hilbert Huang Transform (HHT), for processing the non-linear and non- stationary data. The iterative process of EMD is very time consuming to be run on CPU. Now a days Graphical Processing Units are specialize in handling such processing. Present work incorporates GPU acceleration techniques to achieve high parallelism for fast computation and also for reducing the computational complexity from O(N) on a single CPU to O(N/P log(N)) on GPU[1].**

I. Introduction

Flaw detection of individual component is the key factor in engineering to provide the desired operation and adequate safety for the complete setups eg. aircraft, or submarine or even nuclear reactor. To determine the flaw in the weld requires highly skilled professional in order to interpret the signal and understand its effect on safety. This limits the number of test pieces to be thoroughly tested in a particular time period, by human operator. It is thus planned to design an automated flaw detection system so as to speed up the assessment process. The methods available for processing echo signals from flaws are although very time efficient but question arises for the industrial purpose when the production is in bulk amount, for example the weld verification and some complex structures like turbo machinery in liquid fuel rockets or nuclear fuel elements. Implementation on GPU architectures dramatically speeds up the signal processing paves the way for applications in production type industries. Thus it was aimed to utilize the existing machine (Flaw detector) combined with advanced signal processing techniques to develop a fast analyzing automated system to display the flaws and their size effectively and efficiently with a great speed in less time.

II. Ultrasonic Testing

1. A. Principle

When an ultrasonic wave passing through one medium reaches the boundary of that medium and strikes a dissimilar medium, part of the wave energy is reflected back through the original medium and the remainder is transmitted into the second medium. The reflection also takes place due to the presence of cracks voids and defects in the material. The reflected waves that we receive from these internal defects can be compared to the reflected waves from the external surfaces, enabling the size and severity of internal defects to be identified. Most ultrasonic non destructive test applications range from 400 kHz to 25 MHz, the higher the frequency, the smaller the flaws the system detects, but the depth of penetration decreases.

2. B. Machine Used

The present setup is consists of a hand held Ultrasonic testing device from Olympus model EPOCH XT. This allows the operator to access a wide variety of standard pulsar and receiver features that make the unit flexible to the large number of flaw detector applications. EPOCH-XT incorporates, Pulsar-Receiver assembly, Transducer and Display in a single device and also offers many standard measurement features such as, receiver gain ranging from 0 to 110 dB, selective narrow-band and broad-band digital filters, peak memory and peak hold, and an adjustable PRF.

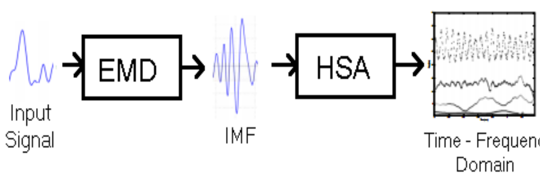

Fig.2: Hilbert Huang Transform[1]

The GageView Pro interface program supplied with the UT system helps manage and format stored inspection data for post-processing. Data can be exported to word processing files and spread sheets for reporting needs. This Program also facilitates to create a customized database of identifier (ID) strings which can be uploaded to the NDT Device. More features includes remote display of live EPOCH XT screens on a PC, Live-Screen Capture mode, database backup/restore, and multi view windows etc.

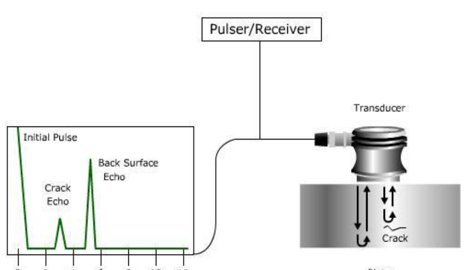

Fig.1: Ultrasonic Testing Principle

III. Hilbert Huang Transform

Processing of stationary signals which have non changing characteristics throughout their time period is a very common aspect in signal processing field, but not for non stationary signals like bird chrip, jack hammer sound, airplane flyover noise. The primary analysis of non stationary signals can be done using Short-Time Fourier Transform (STFT), but it has drawbacks of trade-off between frequency and time resolution. The Hilbert-Huang Transform (HHT) was been proposed by N. E. Huang et al. for signal processing of such type of non-stationary data. HHT is two part algorithms. First one is Hilbert Spectrum analysis (HSA)[1] that constructs energy-frequency-time distribution for the target however HSA cannot be applied to the data where multiple frequencies are mixed, thus second part of this algorithm namely Empirical Mode Decomposition (EMD) is used as a preprocessor to the input data.

A. EMD Overview

EMD is a key feature of HHT, which provides analytical basis functions for the decomposition of the original back-echo flaw signal into a set of some functions (IMF). The idea of EMD is based on a simple assumption that each and every data has some intrinsic modes of oscillations. The data may have different coexisting modes of oscillations, at a given time, superimposing each other. The modes of oscillation are given by an Intrinsic Mode Function (IMF)[1] that has the following definition:

1. The number of extrema and the number of zero- crossing must either be equal or differ at most by 1.

The mean value of the envelope defined by local maxima and the envelope defined by

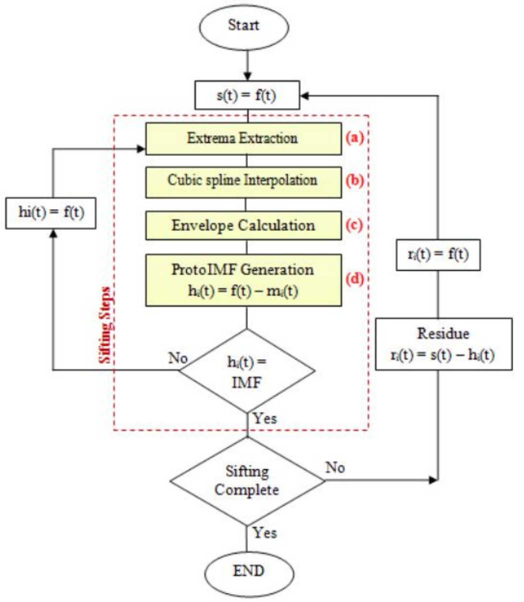

Fig.3: EMD algorithm[4]

local minima should be zero at any point. Mathematically, the original signal f(t) is decomposed through EMD as follows:

$$f(t) = \sum_{i=0}^{n} \mathrm{h_i(t)} + \mathrm{r_i(t)} \qquad \dots (1)$$

Where hn(t) denotes the nth IMF and rn(t) denotes the residue function.

To decompose the signal f(t), first, identify the local extrema (peaks). Connect the local maxima points with cubic spline interpolation, to get the upper envelope. Repeat the previous step for local minima points to get the lower envelope. The mean of both of the envelopes is calculated as mn(t). The mean is subtracted from the original data f(t)to get the first IMF.

$$h_i(t) = f(t) - m_i(t) \qquad \dots (2)$$

If the above function hi(t) does not satisfy the above stated definition of IMF, such function is known as protoIMF and this is considered as new data and same process is simply executed to hi(t) until it reaches the definition of IMF.

When such a hi(t) satisfies the IMF definition, it is considered as the 1st IMF. This IMF is separated from the original signal to get the residue ri(t).

$$r_i(t) = f(t) - h_i(t) \qquad \dots (3)$$

Since the residue ri(t) still contains the longer frequency variations in the data, it is treated as new data and subjected to the same sifting process as above. The process is repeated until ri(t) becomes monotonic function from which no more IMFs can be extracted.

IV. GPU IMPLEMENTATION

Graphic Processing Unit (GPU)[11] were developed primarily to performs the computation for computer graphics mainly texture mapping, shading and rendering polygons etc. These GPU have became highly parallel and multi-threaded and much efficient in handling the processes with large amount of data. CPUs consist single Control Unit and ALU whereas GPU incorporates multiple Control Units and ALUs[11]. In this project, Nvidia Geforce GT980Ti msi GPU, having 2816 CUDA cores and 6 GB RAM is employed.

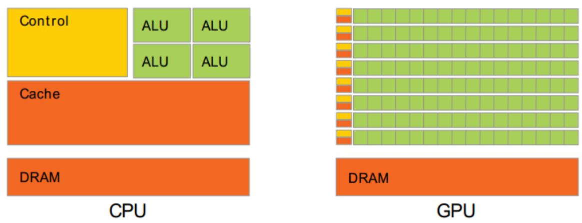

Fig.4: CPU vs. GPU[10]

V. Parallel Extrema Calculation

EMD is a procedure that involves the iterative sifting. Each sifting round performs Extrema Calculation, Cubic Spline Interpolation, Envelope Calculation and IMF Calculation[4].These steps are data-dependent to each other that mean next cannot be executed unless the previous step is completed. Therefore data dependency need to be resolved if the multi threading is applied to the iterative process[1].

In order to achieve the parallelism, two of the above stated processes, Extrema Calculation and IMF Calculation can be executed with GPU. Extrema Calculation involves sorting of peaks (Local Maxima and Local Minima) in the waveform. There is very simple logic behind extrema calculation that is when the value at a particular point is greater than the value at its previous point and not smaller than the value at the next point, that is considered to be as Local Maxima. The similar logic is applied to calculate the Local Minima[4].

```
For i = 0 to residue_iteration
  {
   For j = 0 to IMF_iteration
    {
     // Local Maxima and Local Minima
     // Calculation at device(GPU).
     peaks_max[ ] = gpu.Max(data);
     peaks_min[ ] = gpu.Min(data);

     // cubic Spline Interpolation of
     // extremas.
     Spline_up = CubicSpline(peaks_max);
     Spline_dw = CubicSpline(peaks_min);

     // Mean Calculation and
     // IMF seperation at device(GPU).
     Mean[ ]= gpu.subtract(Spline_up, Spline_dw);
     protoIMF[ ]= gpu.subtract(OriginalData, Mean[ ]);
     data = protoIMF[ ];
    }

   // Residue calculation at device(GPU).
   Residue = gpu.subtract(OriginalData, protoIMF[ ]);
   data[ ]  = Residue;
  }
```

Fig.5: Pseudo Code for EMD

This logic is implemented in the GPU very easily. The process is executed parallel in threads in a block. The thread id is required to compare the data to its adjacent data points. Using this concept, both in the maxima and minima calculations, works in parallel where as to implement the same logic in a CPU required loops in code which takes significant time.

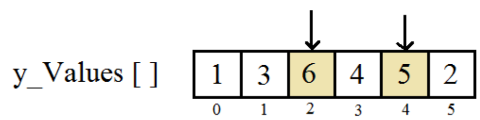

Fig.6: Extrema Calculation

Another stage is IMF generation which is also implemented in parallel processing concept[4]. IMF generation includes subtraction of mean from the original data (equation 2) and also subtraction of IMF from original data to get residue function (equation 3). This is executed in parallel as the subtraction for each data element in array is conducted in a single thread and for each block multiple threads are processed in parallel.

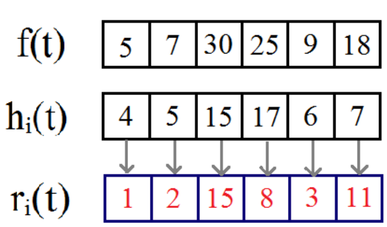

Fig.7: Parallel Residue Calculation

VI. Methodology

Planning and Experimentation

The experimentation setup is developed such that to reduce the latency in the processing and to reduce the human intervention. The flaw detector (EPOCH-XT) sends the electric signals to transducer which then generates and transmits the ultrasonic signal into the test material. The echo signals are received back by the flaw detector which then communicates with the GPU to monitor the crack echoes in the display scope. The test piece is mounted on a two-axis linear translation stage. It is moved in x, y axis and data is acquired at each point on the surface on test piece. The motion of x-y stage controlled through serial port the commands motor controller via computer. The post-processing of signal is performed on the GPU to determine the position and depth of the flaw using the application developed at Microsoft Visual Studio.

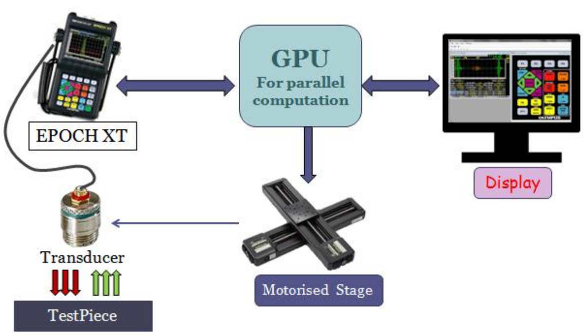

Fig 8: Experimental Setup

VII. Conclusion

This paper presents an application of GPU in Ultrasonic testing for Flaw Detection. The existing system is enhanced by employing advanced algorithm and their execution on GPU. The flaw detection from a small test piece with large number of positions (100 x 100) results in huge data set of echo signal. The Non-Stationary data received back from each position for flaw is processed using Empirical Mode Decomposition. Since EMD is a time consuming process due to its iterative stages, it takes longer time to execute, if run at CPU. Two of its stages are paralleled in GPU, that facilitates fast computation by reducing the time complexity from O(N) to O(N/P log(N)) where P is the number of streaming multiprocessors used.

1. References

1. Pulung Waskito, Shinobu Miwa, Yasue Mitsukura and Hironori Nakajo, "Parallelizing Hilbert-Huang Transform on a GPU," Department of Computer and Information Sciences, Tokyo University of Agriculture and Technology, Koganei, Tokyo 184-8588
2. A Time-frequency Method For Ultrasonic Flaw Inspection Based On HHT Tao Kong, Chunguang Xu, Shiyuan Zhou Key laboratory of Fundamental Science for Advanced Machining Beijing Institute of Technology Beijing, China
3. Zhang Qi, Que Pei-Wen, Liu Qing-kun, Chen Tian-lu, Han Tao, Application of Empirical Mode Decomposition to Ultrasonic Signal Institute of Automatic Detection, Shanghai Jiao-tong University, Shanghai , China.
4. Flexible Parallelized Empirical Mode Decomposition in CUDA for Hilbert Huang Transform,Kevin P.-Y. Huang, Charles H.-P. Wen and Herming Chiueh Department of Electrical and Computer Engineering National Chaio Tung University, Hsinchu 30010, Taiwan.
5. Mingjian Sun, Yi Shen, Wei Zhang, "A Wavelet Threshold Denoising Method for Ultrasonic Signal Based on EMD and Correlation Coefficient Analysis", School of Astronautics, Harbin Institute of Technology, Harbin, China.
6. Yu Wang, "Empirical Mode Decomposition and Rough Set Attribute reduction for Ultrasonic Flaw Signal Classification", School of Software Engineering, Chongqing University of Arts and Sciences, Chongqing, China.
7. Flexible Parallelized Empirical Mode Decomposition in CUDA for Hilbert Huang Transform; Kevin P.-Y. Huang, Charles H.-P. Wen and Herming Chiueh; Department of Electrical and Computer Engineering National Chaio Tung University, Hsinchu 30010, Taiwan .
8. "Application of the Total Focusing Method for Improved Defect Characterization in the Production of Steel Tubes, Pipes and Plates"; Till Schmitte 1, Oliver Nemitz 1, Nikolai Chichkov 1, Thomas Orth 1, 1 Salzgitter Mannesmann Forschung GmbH, Duisburg, Germany.
9. Peel, M.C., G.G.S. Pegram and T.A. McMahon, "Empirical mode Decomposition: Improvement and Application" Department of Civil and Environmental Engineering, The University of Melbourne, Victoria, Civil Engineering, University of KwaZulu-Natal, South Africa.
10. Cliff woolley, "CUDA Overview", Developer Technology Group, NVIDIA.
11. P. J. Narayan, "GPU Architechture: Overview", Centre for Visual Information Technology, IIIT Hyderabad.
12. Ofer Rosenberg, "Introduction To GPU Architechture", PMTS SW, OpenCL Dev. Team, AMD.