Application of a Novel Software Algorithm for Information Reduction in High Frame Rate Ultrasonography

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Abstract: Ultrasonography is a noninvasive method in medical field and is generally used for imaging the abnormal tissue growth. The tissue growth can be benign or malignant and to diagnose the quality of the tissue growth based on the stiffness is a challenge. Orthogonal wave velocity is computed by observing the orthogonal wave propagation in determining the stiffness of a tissue in Ultrasound Transient Elasticity. This requires an ultra-fast scanner which works at frame rates more than 1000 fps. The major difficulty is in collecting huge amount of scanner information and process in the processing system. Hence the designs are very complex and costly. Sliding rectangle algorithm is an innovative approach used in extracting the needed information in measuring the orthogonal wave velocity from successive matrix arrays. In this approach, one image matrix array is integrated into multiple rectangles and in a multi matrix array period, only one rectangle is sent and balance rectangles are discarded. This rectangle is moved multi matrix array to multi matrix array. This information is super imposed on full matrix array information. The orthogonal wave speed is calculated rectangle by rectangle. This algorithm reduces the amount of information sent to the processing system. This will enable the information from the scanner to be ported to Laptops in processing through standard interfaces such as USB or Ethernet in DICOM format. This makes the transient elasticity technology viable to be used in tele-medical field applications.

Keywords: Transient Elasticity, Orthogonal modulus, orthogonal wave velocity, Ultra-fast Scanner, Sliding Rectangle Algorithm, Ethernet, DICOM, Tele-medical field

1. INTRODUCTION

Elasticity measurement is a method used in the computation of tissue stiffness. Elasticity is the natural characteristic of a solid substance which comes back to its original contour after the stress caused by the external forces which caused it distort is taken out. The strain is the relative amount of deformation. The application of ultrasound elasticity in clinical applications is given in [1].

Orthogonal modulus computation using orthogonal wave velocity is given by the equation, $E = 3\rho c^2$where ρ is the density of the tissue. If orthogonal wave velocity is measured, elasticity can be evaluated.

In transient elasticity, low frequency orthogonal waves are induced. The orthogonal wave velocity is measured by cross correlation of the orthogonal wave propagation between the adjacent matrix arrays. Such a method is able to diagnose the tissue growths in a qualitative manner. However in such a qualitative measurement, the precision of the instrument depends upon the distance between adjacent matrix arrays. Though low-frequency orthogonal waves propagate at a low speed of a few m/s in soft tissues, the matrix array rate of the detection system must be higher than 1000 frames/sec to be able to follow their propagation on mm scale [3]. With a frame rate of 800fps and orthogonal wave velocity of 5m/s, a precision of the order of 1mm can be achieved.

Matrix array Rate (FR) is calculated using the equation $\frac{C}{2 \times D \times N}$where C is the ultrasound speed (1540m/s in normal tissues), N is the No. of Scan Lines per frame and D is the Depth of Penetration of the ultrasound waves. Maximum frame Rate is achieved by making N = 1 i.e. all crystals are excited simultaneously.

In an ultrasound machine operating at an ultrasound frequency of 8MHz and a receiver sampling rate of say 24MSPS (Mega Samples Per Second) and an ADC resolution of 8bits, the per sensor channel information rate would be of the order of 192Mbps. The machine has to transfer all the information from all the matrix arrays of all the sensor channels. An ultrasound machine with 64 crystals probe would require around 12Gbps information rate to be transferred from the ultrasound scanner to the processing system. Moreover, receiving such huge amount of information and processing is also a challenge in portable low cost ultrasound machines.

The important considerations in a portable transient elasticity ultrasound machine are as follows. The information / image processing is done in a laptop. The interfacing of the machine with laptop is using standard interfaces such as USB or Ethernet. Standard DICOM interface is used. The scanned information sent from the ultrasound scanner to the laptop is of the order of around 50Mbps in reasonable processing and display in the laptop.

Tele-medical field applications require portable low cost machines which can be taken to remote village locations. The raw information with the selected information size and format or the retrieved video is possible to be sent to a remote location in tele-medical field applications. Peak throughput and TCP rectangle sizes are needed to be evaluated in optimum use of the resources [5]in a Tele-medical field application.

In resolving the above limitations, the output information rates are reduced. Gigabit Ethernet interface, makes it easy to transfer and to view the images immediately on a laptop at a distance away [7]. But the maximum throughput from GE interface is only of the order of 650Mbps. Moreover the

Ethernet interface of the Laptop also is needed to process the complete information. The sliding rectangle algorithm approach presented in this paper is in reducing the information rates without affecting the transient elasticity requirement of measurement of inter matrix array movements.

2. Materials &Methods

2.1 Information Transfer Requirements

In the experimental setup, 32 sensor channels of Transmitter and Receiver are used. The information received from the ADC's are temporarily stored in the RAM available in the field programmable gated array. In the planned ultrasound scanner working at 8MHz, sampling frequency of 24MSPS, ADC resolution of 8bits per sample and PRF of 8 kHz, 3000 bytes of information is to be written per sensor channel. This corresponds to an information rate of 6144 Mbps. In order to reduce the information rates, first an information compression method of peak detection of consecutive 8 samples is carried out. This achieves a compression level of 8 i.e. 375 bytes of information are stored per sensor channel. The information compression reduces the per sensor channel information rates to 24Mbps.Thus in 32 sensor channels, 768Mbps of information is to be transferred. With the additional Ethernet, IP and UDP overheads, the information rates would become around 1Gbps. The planned Sliding Rectangle Algorithm in this paper further reduces the information rates to 45Mbps. This requires 32 Blocks of 375 Bytes RAM storage in the field programmable gated array. With a bus width of 16 Bits, one Block RAM can simultaneously store two sensor channels. Thus 16 Block RAM's of 375 Bytes length would be needed in storing one matrix array of information.

Two separate RAM areas are planned in the read and write operations such that while one matrix array is written into one RAM area, previous matrix array will be read and transferred via Ethernet from the second RAM area. The Ethernet Matrix array is created by the field programmable gated array by multiplexing the information sensor channels and the matrix array bytes of the Ethernet Matrix array, IP/UDP packets. The UDP Source/destination port 104 – Digital Imaging and Communication in Medicine [DICOM] is used as a standard interface protocol.

2.2 Choosing the field programmable gated array

In logic emulation systems the Field Programmable Gate Array (FPGA) provides faster computation as compared to software model. The logic designs are customized in high performance in different types of applications. In multimode system, the field programmable gated array yield significant hardware savings and provides generic hardware in [13]. In order to meet such requirements, Xilinx field programmable gated array with the following specifications is chosen. This device has 172 input/output(I/O Pins), 216K Block RAM, LVDS (Low Voltage Differential Signaling) interface is used in interfacing with High voltage pulsar and the Receiver chips, 622Mbps speed of the IO Bus and EEPROM/Master-Slave/JTAG Programming Headers.

2.3 SlidingRectangle Algorithm

Even though the transient elasticity ultrasound scanner do not possess any limitations in sending the information at these high information rates, the laptops available do not have enough processing capacity in wire rate reception of information at these rates. The main motivation of development of this technique is to reduce the information rate throughput in processing so that the processing can be done in standard hardware such as Laptops. With an ultrasound frequency of f, sampling rate of S, bits per sample as b and number of sensor channels as n, the output information rates typically shall be s*b*n. This information rate is of the order of 1Gbps in the planned system.

Hence an information/image matrix array is integrated into multiple rectangles say 'w' using an algorithm planned in this paper as sliding rectangle algorithm. In this case a w of 23 is taken i.e. the information matrix array matrix is integrated into 23 rectangles and selective rectangles are only transmitted. However in practical implementations, these values and requirements can vary and sufficient flexibility in the methodology can be achieved in choosing the right combinations. Thus the effective information rate is reduced to around 45Mbps. The Sliding rectangle Algorithm is executed in the field programmable gated array.

In the first time, in few matrix arrays, each rectangle is sent one after the other in the low matrix array rate in the MATLAB video reconstruction algorithm to synchronize and reconstruct the full image. Subsequently, the field programmable gated array repeats the first matrix array in 'm' times and discards the balance rectangles before sliding to the second rectangle and so on. This method of repeating the same rectangle 'm' times at the requisite high matrix array rate ensures the measurement of matrix array to matrix array displacement and orthogonal wave velocity without any difficulty. The bottom line is that the used techniques should not hammer the matrix array to matrix array displacement and velocity measurements. In the experimental setup the value of m is taken as 256.

2.4 SlidingRectangle Algorithm Flow Chart

The flow chart of the receive field programmable gated array in the implementation of Sliding Rectangle Algorithm is shown in the figure-1 below.

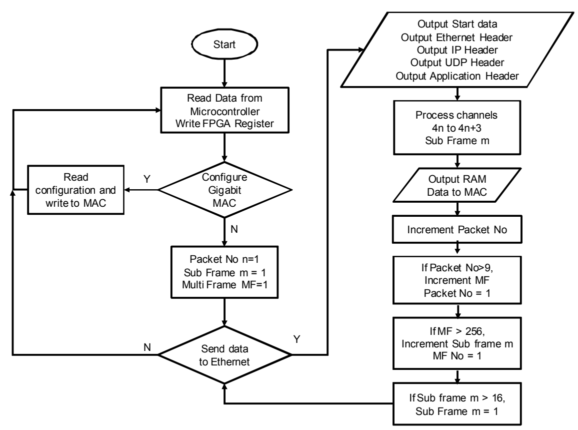


Figure-1: Receive field programmable gated array software algorithm flow chart

In the experimental setup described in this paper, 368 Bytes of information per sensor channel is read out of the field programmable gated array through the Ethernet port. The 368 Bytes are integrated into 23 rectangles. I.e. each rectangle comprises of 16 bytes per sensor channel or 16 x 32 Bytes per ultrasound matrix array. During one write sequence to the field programmable gated array, only one rectangle of 16 x 32 bytes is transferred to the laptop and balance information is discarded. A multi matrix array consists of 256 such sub matrix arrays where in only the first matrix array is only read. Once one multi matrix array is read, it moves on to read the next rectangle and so on. This algorithm reduced the effective output information rate by 23. This also ensured that the high matrix array rate is retained so that the measurement of matrix array to matrix array displacement and hence the transient wave velocity is not affected.

Video reconstruction algorithm in MATLAB does intelligent algorithm. Based on the initial consecutive rectangles, the first image is reconstructed. Subsequent matrix arrays are superimposed on the initial matrix array. In enabling this arrangement of rectangles and matrix arrays, the rectangle id and matrix array id are sent along with the packet in the UDP payload. The rectangle matrix is superimposed on the complete matrix array matrix and image is displayed. Since motion detection calculates the difference between the matrix arrays, orthogonal wave motion is detected in the sliding sector.

3. IMPLEMENTATION & MODEL

3.1 General Working Procedure

The Tx field programmable gated array generates the Transmit pulses at 8MHz and at a PRF of 8kHz in all the sensor channels.8 Sensor channel High Voltage Pulser consists of logic interfaces and amplifies the digital pulses generated by the field programmable gated array in exciting the piezo electric crystals located in the Ultrasound transducer probe. The 8 sensor channel receiver has LNA to amplify the low level receive data received from the piezoelectric crystals, TGC in Time Gain Compensation, AAF – the Anti Aliasing Filter and the ADC which performs the Analog to Digital Conversion. TGC implementation in ultrasound, see [18].

The Receive field programmable gated array has sufficient I/O Buses in interfacing with the ADC's, Ethernet MAC and the Microcontroller as given in the Figure-2 below. Serial Peripheral Interface [SPI] programming infield programmable gated array, see [9]

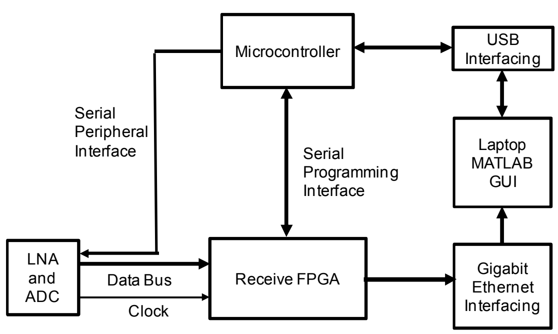


Figure-2: Block schematic of the Receive portion of Ultrasound Scanner

3.2 Storing the receive information in the field programmable gated array RAM using two information banks

The LNA supplies two clocks FCO and DCO in synchronizing and reading the information by the field programmable gated array LVDS Receiver. Various clocks needed in receiving and processing of the information is generated in the field programmable gated array. The internal RAM of the field programmable gated array acts as the temporary storage of the scanned information. The receive information is converted into serial to parallel stream and stored in the field programmable gated array Block RAM. Two Block RAMs of the field programmable gated array are used in writing the alternate matrix array of information. Thus the field programmable gated array requires two information banks, which will be switched between the write and read operations. The interface logic is embedded in Field Programmable Gate Array and therefore the field programmable gated array includes both user logic and interface logic [11].

Likewise all the 32 sensor channels of receive information are written into the information banks. 375 Bytes per sensor channel is stored in the field programmable gated array information bank.

3.3 Storing Overhead information infield programmable gated array Registers

The overhead information in the Ethernet Matrix array, IP Packet and UDP information are stored in the field programmable gated array Registers. Some of these information values are fixed values where as some of the values like source, destination IP addresses etc are assigned by the Microcontroller. The Microcontroller in turn is programmed from the MATLAB graphical user interface through the USB interface as shown in Figure-2.

3.4 Field programmable gated array Receive Packet Information Architecture

The field programmable gated array receive packet formation system architecture uses the Sliding rectangle algorithm. The information header generated by the field programmable gated array contains the MAC Information write start bytes, Ethernet header Information, IP Header Information and the UDP Header Information. After sending the information headers, the information from any one of the field programmable gated array RAM information bank is read using the Sliding Rectangle Algorithm. On completion of the information read, the MAC information write stop bytes are sent which will enable the MAC to send the complete packet to the Ethernet interface. This is given in Figure-3 below.

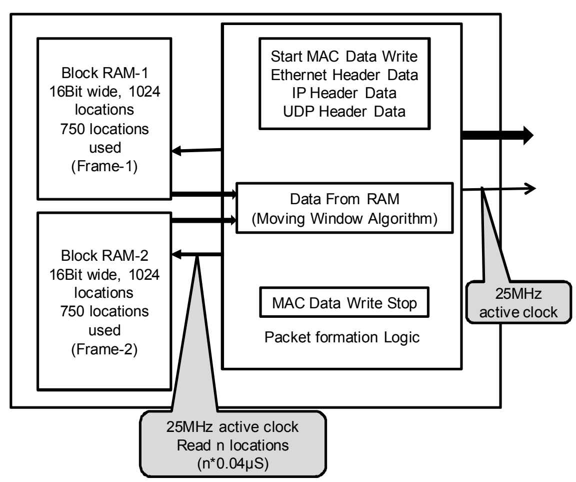


Figure-3: Receive field programmable gated array logical block schematic

The pipelined architecture of the Field Programmable Gate Array and the distributed Random Access Memory in high I/O resources of an image classifier implementing object classification stages in object detection system is discussed in [15].

Some of the header bytes like the checksum etc are written into the Ethernet matrix array by the Gigabit Ethernet MAC chip. All other headers are written through the microcontroller into the field programmable gated array registers. The Gigabit MAC chip also requires the start and stop bytes from the field programmable gated array. A counter is used in sending the information sequentially in the order of start bits, Ethernet header, IP header, UDP header, Application header, Information from the block RAM, Ethernet end of matrix array and stop bits. The information is transferred at very high speeds to the Gigabit Ethernet MAC chip.

Gigabit Ethernet controller maintains full duplex operation with 1000Mbps information Rate, High-performance non-PCI local bus, EEPROM interface and 16/32-bit SRAM-like host interface. It does the Ethernet framing of the information and inserts the IP and UDP header checksums. Physical Layer (PHY) devices maintain 1000BASE-T standards in full-duplex mode, and maintain the RGMII interface operating at 125MHz towards the Gigabit Ethernet controller. It carries out the Physical layer level translations and conversions to Gigabit Ethernet speeds over copper interface.

The information processing and image processing is carried out in the MATLAB based graphical user interface. The device configurations are controlled from the graphical user interface through a microcontroller in the Ultrasound board.

3.5 Model Results

The model results of various waveforms of host clock, RAM enable clocks etc can be seen in the figure-4 below. The various clocks generated by the field programmable gated array including the RAM read clocks from different information banks are seen in the figure.

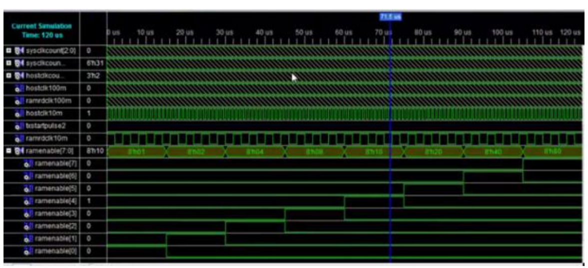
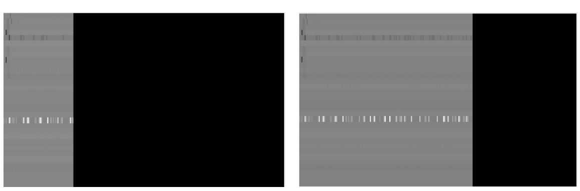


Figure-4: Model results during the design phase using field programmable gated array

4. RESULTS

The image reconstruction using the slidingrectanglein a MATLAB graphical user interface is given in the Figure-5. The image is progressively getting reconstructed in this method. The final image can be seen in Figure-6.



(a) (b)

Figure-5: Sliding rectangle Algorithm display in MATLAB graphical user interface with (a) 4 and (b) 10 Rectangles

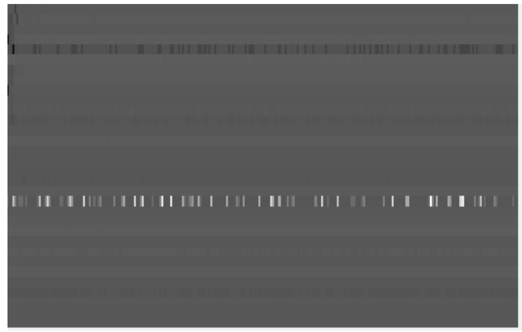


Figure-6: Final acquired image after the slidingrectangle algorithm on a homogeneous medium used as phantom

Further, the displacement of the propagating orthogonal wave is measured as a function of time and space in [18] using MATLAB based algorithms.

Transient elasticity measurements require the cross correlation measurements between successive matrix arrays which are sliding at matrix array rates of the order of 1000fps.In this method, one rectangle is continuously transmitted in say256 matrix arrays. Hence the velocity of propagation of the orthogonal waves can be measured within the rectangle using the existing methods. This method is repeated in successive rectangles and the resultant velocity graph is combined to get expected results. The arrival time envelope satisfies the Eikonal equation. The distance method is used to solve the inverse Eikonal equation given the arrival times of a propagating wave, to find the wave speed [17].

5. DISCUSSION AND CONCLUSION

In observing the orthogonal wave propagation and to compute the orthogonal modulus, an ultrafast scanner is needed which works at matrix array rates more than 1000 fps. Such ultrasound machines are needed to collect huge amount of scanner information and process the same in the processing system. This makes their design very complicate and expensive. Hence the algorithm helps.

Through this paper, a new algorithm named Sliding rectangle algorithm is introduced which is found to be an innovative approach by extracting the needed information in measuring the orthogonal wave velocity from successive matrix arrays.

In this approach, one image matrix array is integrated into multiple rectangles say 16 and in a multi matrix array period, only one rectangle is sent and balance rectangles are discarded. This rectangle is moved multi matrix array to multi matrix array. This information is super imposed on full matrix array information. The orthogonal wave speed is calculated rectangle by rectangle. This algorithm reduces the amount of information sent to the processing system. This will enable the information from the scanner could be ported to Laptops in processing through standard interfaces such as USB or Ethernet. This makes the transient elasticity technology viable to be used in tele-medical field applications.

6. ACKNOWLEDGEMENTS

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