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Implementation of Fast Discrete Curvelet Transform using Field-Programmable Gate Array

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ABSTRACT

A multidirectional of Fast Discrete Curvelet Transform (FDCT) have the advantages of Fast Fourier Transform (FFT) at a given scale and orientation and have been used widely in image processing applications such as enhancement, de-noising and fusion. However, the area of image compression along with hardware implementation is not exclusively touched. Thus, this paper presents an approach towards compression algorithm development using FDCT. The proposed algorithms were synthesized using MATLAB and implemented on NI sbRIO-9607 (XC7Z020) Field-Programmable Gate Array (FPGA). Three different types of medical modalities; computed tomography (CT), positron emission tomography (PET) and magnetic resonance imaging (MRI) are used as an input image. The implementation results show that it achieves a high compression ratio (70.72%) for PET image. Whilst, the MRI image provide a higher value of peak signal to noise ratio (PSNR) (19.9 dB). Moreover, the results provide better achievement in terms of area (3.5%) and maximum frequency (302 MHz).

Key words : FDCT, FPGA, Image Compression.

1. INTRODUCTION

New technology has introduced a large number of image processing applications in diverse human activities such as automatic visual inspection system, criminal detection in videotelephony system, astronomical analysis system and remotely sensed scene interpretation [1] - [3]. Interestingly enough, biomedical imaging applications are growing explosively for the purpose of medical diagnosis [4] - [6]. Thus, it is important to take a look at the technique and method used in medical image processing system including the storage processing, transmission, recognition and interpretation of visual scenes [7], [8].

The principle cause of deaths issued by the Ministry of Health Malaysia (MOH) Hospitals have reveal that cancer was the third common cause of death in Malaysia. As the total number of new cancer cases to be diagnosed is increasing, it directly causes a real demand of data storage [9], [10]. This is due to the more widespread use of 3-D imaging modalities such as CT, MRI and PET that have generated a massive amount of volumetric data [11]. In addition, the most medical imaging modalities used are CT, MRI, PET and ultrasound. The result produced from the modalities is in a form of image, whereas the image carries a lot of information belong to the patient. In fact, the increasing number of patients every year will directly increase the medical image generated. As a consequence, a large size of data storage is needed to stores the medical images.

In these fields, medical image compression become the best solution to compress the image without degrading the quality of the image [12], [13]. At the same time, it offers efficient data storage and high-bandwidth. Generally, there are three processes included in the image compression system; transformation, quantization and entropy coding. The first step specified the bits available and tolerable error parameters of the target image before dividing the image data into various classes. Then, each image data is quantized separately using the bit allocation information. Finally, the image data is encoded separately using entropy coder. In fact, the important process to compress an image is to transform the integer values to a new set of numbers before the quantize and encode process is applied [14], [15].

In the context of transformation algorithms, several methods have been used such as Discrete Cosine Transform (DCT) [16], [17], Discrete Wavelet Transform (DWT) [18], [19], Ridgelet Transform [21], [22] and recently is Curvelet

Transform [20], [21]. Even though the DWT has advantages of multiresolution analysis, but it has limitations to represent the coefficients along curves [22]. Contrariwise, the Curvelet Transform is less redundant in analyzing the edges of an image [23]. Generally, there are two generations of Curvelet Transform. The first generation is called a Continuous Curvelet Transform and it used a series of steps involving the Ridgelet Transform analysis. On the other hand, the second generation is developed to overcome the complexity of Ridgelet Transform analysis in the first generation and known as FDCT. This second generation is faster and simpler compared to the first generation [24], [25].

Despite most of the transformation algorithm developments have been proposed [26], [27], but the algorithm implementation into a suitable hardware is still open for research. Interestingly, the reconfigurable hardware in the form of FPGA emerges as a practicable device in the construction of a complex system. Besides have a multimillion number of gates, FPGA also offers advantages of parallelism capabilities and low-power consumption [28].

This paper presents implementation of Fast Discrete Curvelet Transform (FDCT) using FPGA. The aim of this paper is to develop an efficient transform algorithm using FDCT. The proposed algorithms were synthesized using MATLAB and implemented in NI sbRIO-9607 FPGA board and the performance evaluation is carried out in terms of PSNR, compression ratio (CR), area and maximum frequency.

The rest of the paper is organized as follows. An overview of the related work is summarized in Section 2. Section 3 describes the mathematical background of FDCT. The methodology is explained in Section 4. Section 5 discusses the experimental results and finally, conclusions and further potential ideas is given in Section 6.

2. RELATED WORKS

A close examination of the transform algorithms used in image processing applications has revealed that the DCT, FFT and DWT algorithms are the most practiced [29] - [31]. Recently, the curvelet transform has been explored in image processing applications such as image enhancement, image de-noising, image fusion and image compression. In addition, the image processing applications involves with a matrix operation, whereas it is a complex mathematical operation [32]. A medical image contains a lot of information that belongs to the patient and thus it has a large size compared with the standard image. The computational complexity for the matrix transform algorithms is in the order from $O(N \times \log N)$ for FFT to $O(N^2 \times J)$ for the curvelet transform; where N is the transform size and J is the maximum transform resolution level.

An efficient implementation of the transform algorithms has been a topic interest for a better compression system [33]. The target of the compression system is to extract useful information and remove redundant information and at the same time reducing the size of the image. Furthermore, the computational complexity for the matrix transform algorithms becomes a challenge in hardware implementation fields and requires more concern [34].

Currently, the curvelet transform algorithm has been used in image processing applications [35], [36] besides the others transform algorithms such as DCT, FFT and DWT. However, exploration works on the implementation of the algorithm with a reconfigurable device were still untouched widely.

As can be seen from the existing implementation [37] - [39] there still remains a huge gap for further research in exploiting reconfigurable computing for medical image compression. Moreover, there are two major limitations can be identified as follows:

1. Image compression is one of the well establish research area. But, medical image compression especially dealing with FDCT algorithms is considered as a pre-mature area; and
2. Hardware implementation for medical image compression has not been intensively addressed using the FDCT algorithms.

Interestingly, FDCT has led to a revolution in the image coding algorithm. It consists of three parameters; number of scales, orientation and angular panels. Moreover, it produces three different frequencies which are low, middle and high frequency.

3. SECOND GENERATION OF CURVELET TRANSFORM

The FDCT algorithm is one of the high dimensional wavelet transforms used to analyze the image with different number of scales, orientations and angular panels. The curvelet transform is a multidirectional and the frame element is indexed by using scale and location parameters. Furthermore, in the curvelet domain, the information of prominent edges in images is wrapped into a small number of coefficients called cells.

The FDCT is defined by pair of windows; radial window *{W(r)}* and angular window *{V(t)}*. Equation (1) represents polar wedge U_j.

$$U_j(r,\theta) = 2^{-3j/4} W\left(2^{-j} r\right) V\left(2^{j/2} \frac{\theta}{2\pi}\right) \quad (1)$$

In fact, the multiresolution discrete curvelet transform have the advantage of FFT at both the image and curvelet. Refer to (2), the calculated FFT images, curvelet and inverse FFT (IFFT) values are used to generates the curvelet transform coefficients.

$$Curvelet = IFFT\left[FFT\left(Curvelet\right) * FFT\left(\mathrm{Im}\,age\right)\right] \quad (2)$$

To determine the number of scales, orientations and angular panels, refer to (3), (4) and (5) respectively.

$$N_{scales} = ceil\left(\log_2\left(\min\left(N_1, N_2\right)\right) - 3\right) \quad (3)$$

$$\ell_j = 16 \times 2^{ceil\left(\left(N_{scales} - i\right)/2\right)} \quad (4)$$

$$n_{quad-j} = 4 \times 2^{ceil\left(\left(N_{scales-i}\right)/2\right)} \quad (5)$$

The curvelet transform based on wrapping method takes a 2-D image as an input in the form of a cartesian array $f\left[n_1, n_2\right]$, where $0 \le n_1 < N_1, 0 \le n_2 < N_2;\ \ N_1 \& N_2$ are the dimensions of array. Furthermore, the orientation of the curvelet at angle θ generates the same coefficients (redundant values). Thus, only half of the sub bands at orientation $\pi + \theta$ can be used.

4. PROPOSED SYSTEM ARCHITECTURE

Figure 1 shows the proposed system architecture using FDCT. It overviewed the image compression system including the transform, quantization and entropy coding blocks. Moreover, a buffer is located at each block to store the intermediate results. The goal of this paper is to propose an adaptive compression system for a medical image with reconfigurable properties applied to the transformation block.

The input image is fed into the transformation block and their pixels are processed with the FDCT algorithm. The low frequency filter produces the curvelet coefficients at the finest scale, while the medium frequency filter generates the curvelet coefficients at the middle scale. Finally, the high frequency filter obtains the curvelet coefficients at the coarse scale

As illustrated in Figure 2, the image is decomposed into five scales and the number of angular panels is set to sixteen. The Cartesian concentric coronae show the curvelet coefficients at different scales. The curvelet coefficient at the center of the display (at scale 1) is the low frequency and also called as coarse scale. Whilst, the outer coefficient is the high frequency (at scale 5) and also known as finest scale.

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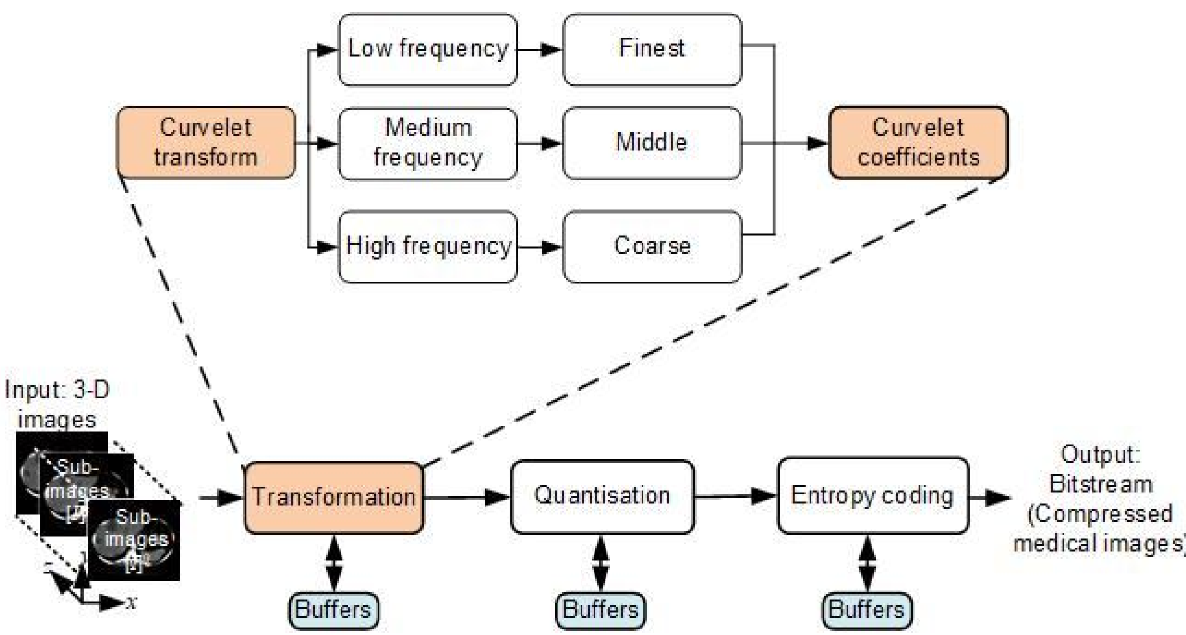


Figure 1: Proposed System Architecture.

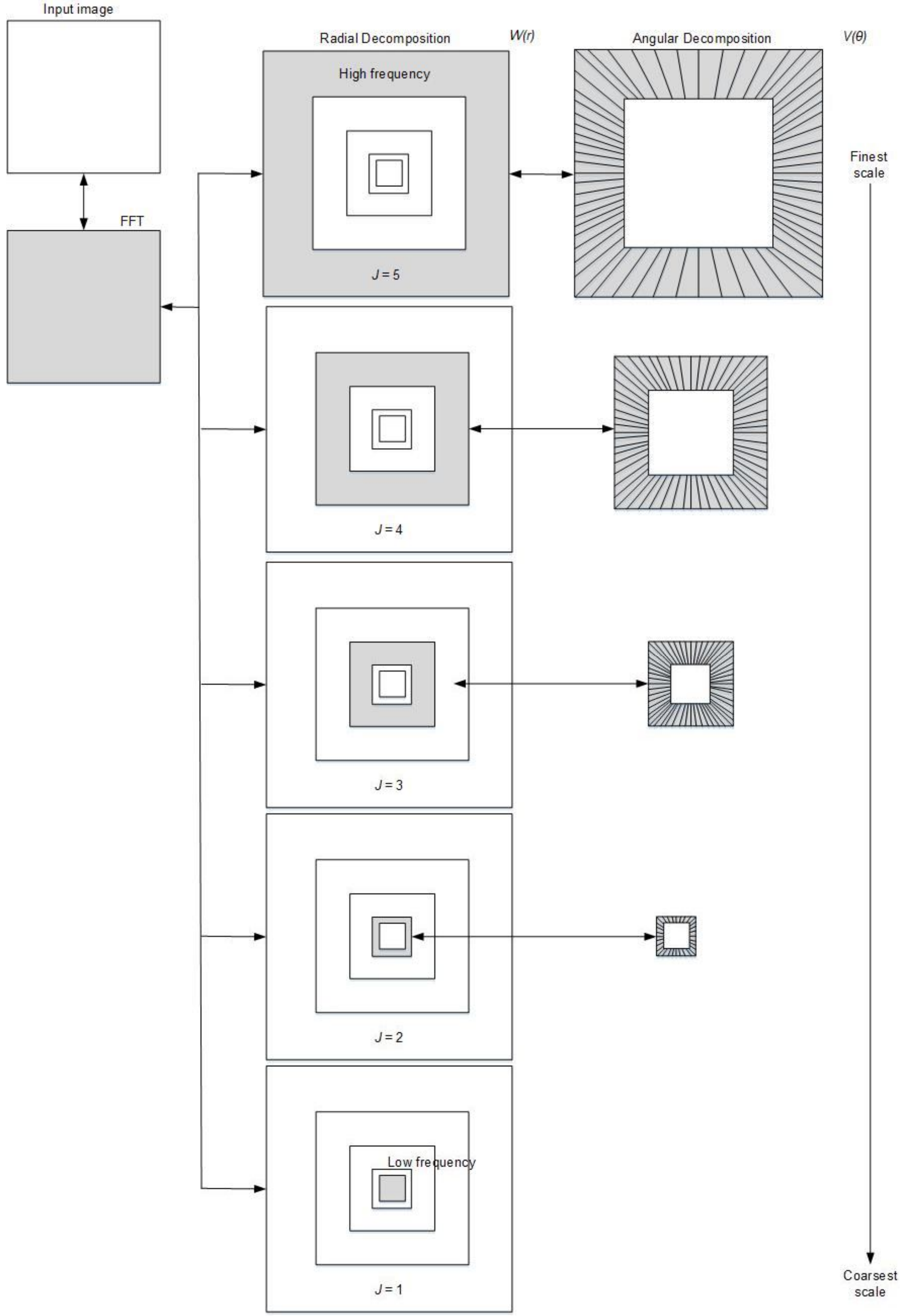


Figure 2: Structure of the FDCT Algorithm.

5. RESULTS AND DISCUSSIONS

The proposed architecture has been synthesized and implemented on the Xilinx Zynq-7010. To evaluate the performance of the proposed architecture, four parameters have been selected including PSNR (dB), CR (%), area (slices) and maximum frequency (MHz). Moreover, three different types of medical modalities such as CT, PET and MRI are used as the input image.

Table 1 summarize the overall performance results for the proposed architecture in terms of PSNR and CR. The results show that it achieves a high value of CR (70.72%) for PET image. Whilst, the MRI image provides a higher value of PSNR (19.9 dB).

A comparison between the proposed architecture with the previous work (implemented on Xilinx Spartan-3) also carried out in Table 2. From the table, the proposed architecture with FDCT algorithm provides better performance results in terms of area and maximum frequency compared to the proposed architecture using DCT in [40].

Table 1: Implementation results

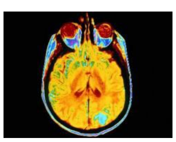
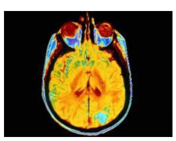
Original image	Reconstructed image	Parameters
MRI brain 		• PSNR:19.9 dB • CR: 51.70%
PET brain 		• PSNR:11.6 dB • CR: 70.72%
CT brain 		• PSNR:10.3 dB • CR: 64.98%

Table 2: Overall performance and comparison with previous work

Parameters	Proposed architecture	E. Iman *et. al* [40]
Transform algorithm	FDCT	DCT
Device	Zynq-7010	Spartan-3
Area (Slices)	2980/85,000 (3.5%)	3381/5888 (57%)
Maximum frequency (MHz)	302	NA

6. CONCLUSION

This paper presents the implementation of FDCT algorithm using FPGA. An efficient architecture for medical image compression system using FDCT algorithm have been proposed. A comparative study has revealed that the FDCT algorithm provides better achievements in terms of area and maximum frequency compared to the DWT algorithm. Moreover, the FDCT algorithm is suitable to be applied with the PET image because it obtains high CR compared to CT and MRI images.

On-going research is focusing on the implementation of FDCT using distributed arithmetic and systolic array techniques. Furthermore, the implementation with different reconfigurable devices will be further explored especially in terms of power consumption to demonstrate the efficiency of the proposed architecture in medical image compression system.

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