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Dyadic wavelet for image coding implementation on a Xilinx MicroBlaze processor: Application to neutron radiography

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HIGHLIGHTS

- Research Reactor utilization for industrial imaging.
- Neutron radiography projections transmission through a network.
- Mixed reconfigurable Software/Hardware implementation.
- Fast Wavelets transform for image compression.
- Huffman Encoding/Decoding of the transmitted images.

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ABSTRACT

In this work, we present a mixed software/hardware implementation of 2-D signals encoder/decoder using dyadic discrete wavelet transform (DWT) based on quadrature mirror filters (QMF); using fast wavelet Mallat's algorithm. This work is designed and compiled on the embedded development kit EDK6.3i, and the synthesis software, ISE6.3i, which is available with Xilinx Virtex-IIV2MB1000 FPGA. Huffman coding scheme is used to encode the wavelet coefficients so that they can be transmitted progressively through an Ethernet TCP/IP based connection. The possible reconfiguration can be exploited to attain higher performance. The design will be integrated with the neutron radiography system that is used with the Es-Salem research reactor.

1. Introduction

A digital radiological image is an image acquired via a radiological process, including X-rays, neutron radiography, and gamma camera imaging or nuclear magnetic resonance imaging. It is a two-dimensional $M \times N$ array of non-negative integers (gray levels). For tomography, the gray level value represents the relative linear attenuation coefficient of the object. The performance of radiological image compression depends not only on the compression ratio, but also on the quality of the reconstructed images. Higher quality images show finer structural or functional information of body organs and support more reliable diagnostic outcomes (Wong. et al., 1995). However, there should be no statistically significant differences – in observer performance – between an acquired raw image and the best-quality image (Doyle et al., 2005). In other words, there should be no difference in the correctness of observer performance in the final user diagnostics of in-site neutron radiographs compared with those after compression, transmission and enhancement. In a previous report (Gilbert and Lemke, 2005), the authors showed that in cancer cases, the lack of prompts can have a detrimental effect on the sensitivity of image readers. This became particularly apparent when difficult cases were being read and as such, the authors suggested that the readers use computerized images as a decision making tool instead of a prompting aid. Several

Abbreviations: CWT, Continuous Wavelet Transform; DWT, Discrete Wavelet Transform; QMF, Quadrature Mirror Filter; FPGA, Field Programmable Gate Array; HDL, Hardware Description Language; UART, Universal Asynchronous Receive Transmit; DDRAM, Dynamic Data Random Access Memory; RLE, Run Length Encoder; GPIO, General Purpose Input/Output; MDM, Microprocessor Debug Module; BRAM, Block Random Access Memory; XMD, Xilinx Microprocessor Debugger; MSE, Mean Square Error; PSNR, Peak Signal to Noise Ratio; CCD, change-coupled Device

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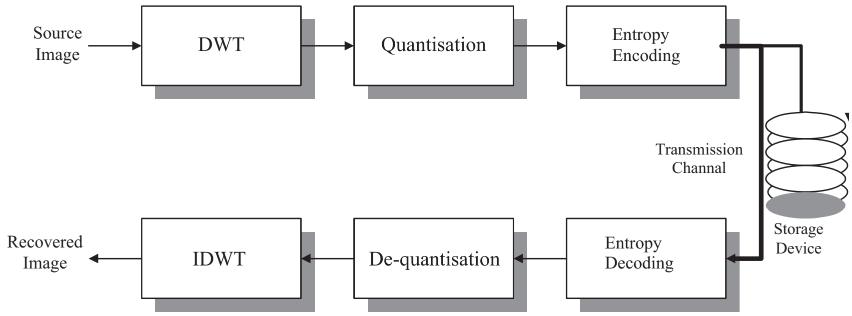

Fig. 1. Wavelet-based encoding scheme (Masud, 1999).

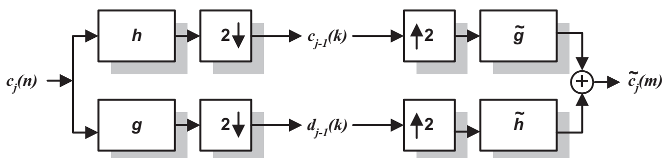

Fig. 2. One dimensional discrete wavelet transform.

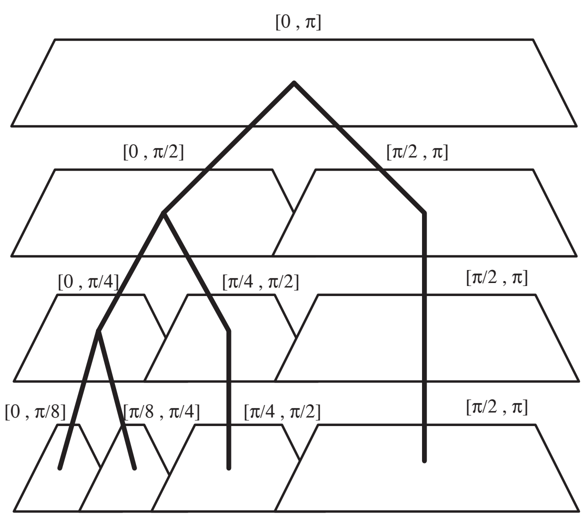

Fig. 3. Frequency spectra.

studies have investigated the impact of image quality on diagnostic performance, and it has been shown that high image quality does not guarantee correct diagnostic outcomes (Mark et al., 2013).

Neutron radiography imaging has been widely used in industrial applications, such as the detection of a particular material in an assembly containing two or more materials, and non destructive assays of turbine blades, electronic packages and aerospace structure like metallic honeycomb and composite components, valves and other assemblies.

Wavelet transform has been successfully applied to different fields, ranging from pure mathematics to applied science (Nibouche et al., 2000). Numerous studies on wavelet transform, have proven its advantages in image processing and data compression and have established its use as a basic encoding technique in recent data compression standards (Lewis and Knowles, 1992). Solely implementing discrete wavelet transform software, however, appears to present a problem when real time systems are required in terms of performance (Amato et al., 2000). Therefore, hardware acceleration of the DWT has become a topic of recent research (Corsonello et al., 2005).

The basic motivation of our application to neutron tomography projections is to reduce data volume and to achieve a low bit rate in the digital representation images without apparent loss of image quality to achieve high-quality 3-D reconstruction on a distant computer or storage device for future retrieval. In this study, we incorporated this implementation, in addition to image restoration (Saadi et al., 2012; Saadi et al., 2013), to the whole neutron imaging system (Kharfi et al., 2011).

Our approach for image compression can significantly improve 2-D image storage and transmission. It is based on the collection of projection images, encoding/decoding, TCP/IP transmission and 3-D reconstruction. The design is based on the Mallat's fast wavelet transform algorithm, which is a fast implementation of the discrete wavelet transform. The design utilizes various digital techniques and specific features of the Xilinx FPGA to accelerate the transform. Furthermore, the reconfigurable property allows modification at any stage of the design which is optimized for any FPGA type (Touiza et al., 2013).

2. Image compression framework

The general framework for radiological image compression based on wavelet transform, see Fig. 1, is similar to other digital compression fields, and includes the following three major stages: image transformation, quantization (irreversible compression only) and entropy encoding. The relative importance of each stage varies from one technique to another and all reversible compression techniques do not involve the stage of quantization (Mallat, 1989). It is useful to consider entropy encoding as a two-step process.

The first step uses a statistical model to convert coefficients into an intermediate sequence of symbols. The second step converts the symbols to a data stream in which the symbols no longer have externally identifiable boundaries. The entropy coding uses a variable-length code, such as Huffman coding, to achieve higher compression rates. The same code tables used to compress an image are needed to decompress it. A promising approach of image compression is progressive transmission, which transmits image data in stages, and, at each stage, reconstructs an approximation of the original image at the receiver.

A radiological image compression algorithm that provides multi-resolution image representation offers many advantages.

Formally, the wavelet transform is defined by many authors as a mathematical technique in which a particular signal is analyzed or synthesized in the time domain by using different versions of a dilated or contracted and translated or shifted basis function called the wavelet prototype or the mother wavelet.

The CWT as defined by Morlet and Grossman (Masud, 1999) is as follows:

$$W(a,b) = \frac{1}{\sqrt{a}} \int_{-\infty}^{+\infty} f(t)\psi^*\left(\frac{t-b}{a}\right)\, dt \tag{1}$$