Efficient Enhancement-Driven Image Compression For a Range of Medical Images and FPGA Deployment with Vivado HLS

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Abstract-
This paper proposes an Optimal Enhanced-Based Image Compression (OEIC) method designed to achieve superior performance in terms of compression ratio, image quality, and processing efficiency. The method leverages advanced algorithms and modern hardware capabilities to provide a high-efficiency solution suitable for various applications, including medical imaging, digital photography, and web usage.

Keywords: OEIC, Image Compression, FPGA Implementation.

I INTRODUCTION
Medical imaging has revolutionized healthcare by enabling non-invasive diagnosis and monitoring of various conditions. However, the large size of medical image files poses significant challenges for storage, transmission, and processing, especially in telehealth and remote diagnostics applications. Efficient image compression techniques are crucial to address these challenges, ensuring that medical images can be stored and transmitted without compromising diagnostic quality. This paper explores the comparative performance of various medical image compression formats and their implementation using Field-Programmable Gate Arrays (FPGAs) with Vivado High-Level Synthesis (HLS). FPGAs offer a flexible and efficient platform for accelerating image processing tasks, providing the capability to handle real-time data with lower latency and higher throughput compared to traditional software-based approaches.
Vivado HLS facilitates the conversion of high-level programming languages, such as C/C++, into hardware descriptions, streamlining the development process and enabling rapid prototyping and optimization of complex algorithms. By leveraging Vivado HLS, this study aims to evaluate the feasibility and performance of different compression formats when implemented on the Arty Z7-20 development kit.

The objectives of this research are twofold: first, to identify the most efficient compression format for medical images based on compression ratio, image quality, and processing speed; second, to demonstrate the practical implementation of these formats on an FPGA, highlighting the advantages and potential challenges of using hardware acceleration in medical imaging applications. This comparative study will provide valuable insights into the trade-offs between different compression techniques and the benefits of FPGA-based implementations, contributing to the advancement of efficient and reliable medical imaging solutions.

II CURRENT APPROACH

Medical Image Compression Techniques

Medical image compression is a critical area of research aimed at reducing the size of medical images without significantly compromising their quality. Various compression techniques have been explored to address this challenge, broadly classified into lossless and lossy compression methods.

Lossless Compression

Run-Length Encoding (RLE): Suitable for images with large homogeneous regions, RLE compresses sequences of identical pixels effectively.

Huffman Coding: Utilizes variable-length codes for different pixel values based on their frequencies, ensuring no data loss.

Lempel-Ziv-Welch (LZW): Widely used in formats like GIF and TIFF, LZW replaces repetitive sequences with shorter codes.

Lossy Compression

JPEG and JPEG2000: JPEG is the most common lossy compression method, using Discrete Cosine Transform (DCT) to transform image data into frequency components. JPEG2000, an improvement over JPEG, uses wavelet transforms to provide better compression efficiency and image quality. Fractal Compression: Exploits self-similar patterns in images, achieving high compression ratios but with higher computational complexity. Transform Coding (e.g., DCT, Wavelet): Transforms the image data into a different domain where compression is more efficient. Wavelet transform is particularly effective for medical images due to its ability to preserve important features.

FPGA Implementation Using Vivado HLS

FPGAs offer significant advantages for real-time image processing applications due to their parallel processing capabilities and reconfigurability. Vivado HLS, a tool from Xilinx, allows developers to convert high-level descriptions in C/C++ into hardware descriptions (HDL), significantly simplifying the development process for FPGA implementations.

Advantages of FPGA for Image Processing

Parallelism: FPGAs can perform multiple operations concurrently, drastically improving processing speed.

Flexibility: FPGAs can be reprogrammed to accommodate different algorithms and processing needs.

Low Latency: Direct hardware execution of algorithms reduces latency compared to software-based implementations.

Vivado HLS in Image Compression

Design Flow: Vivado HLS converts high-level algorithm descriptions into synthesizable VHDL/Verilog code, optimizing for area, speed, and power.

Case Studies: Several studies have demonstrated the efficacy of using Vivado HLS for image processing tasks. For instance, Xilinx provides examples of image filtering, edge detection, and compression implemented using HLS.

Performance Metrics: Key performance indicators for FPGA implementations include compression ratio, latency, resource utilization (LUTs, BRAMs), and power consumption.

Comparative studies

Numerous comparative studies have evaluated the performance of different image compression techniques on FPGAs. For example,

JPEG vs. JPEG2000:

JPEG: Faster and less complex, but with lower compression efficiency.

JPEG2000: Higher compression efficiency and better quality, but with increased computational requirements.

Wavelet vs. DCT-based Methods:

Wavelet Transforms: Offer better performance for medical images due to their multi-resolution analysis capability.

DCT: Simpler and faster but may not preserve critical image features as effectively as wavelet-based methods.

FPGA vs. GPU/CPU Implementations:

FPGA: Offers superior performance in terms of latency and power efficiency for real-time processing tasks.

GPU/CPU: Easier to program and more flexible for a wide range of applications but may not meet the stringent real-time requirements of medical image processing.

III MATERIALS AND METHODS

Proposed Optimal Enhanced based Image Compression

The OEIC method uses **MATLAB IN BUILT USER DEFINED FUNCTIONS** to integrate several advanced techniques to optimize the compression process:

Hybrid Transform Coding:

Combines Discrete Cosine Transform (DCT) and wavelet transforms to exploit their respective advantages in different image regions. DCT efficiently compresses smooth areas, while wavelet transforms handle edges and textures more effectively.

Adaptive Quantization:

Dynamically adjusts the quantization parameters based on the image content to balance compression ratio and image quality. Ensures that important image features are preserved while achieving high compression rates.

Entropy Coding:

Utilizes advanced entropy coding techniques such as Arithmetic Coding or Context-Adaptive Binary Arithmetic Coding (CABAC) for lossless compression of the quantized data. Maximizes compression efficiency by reducing redundancy.

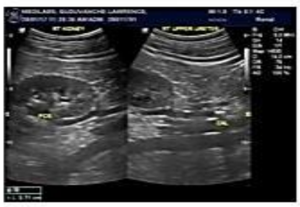
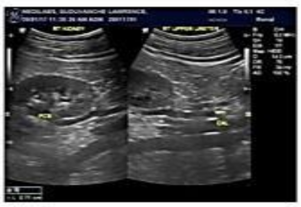
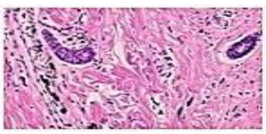
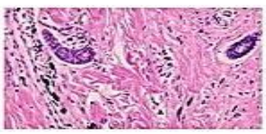
Optimized Rate-Distortion Algorithm:
Implements a rate-distortion optimization strategy to minimize the visual distortion for a given compression rate. Ensures that the compressed image maintains high visual fidelity.
Parallel Processing with FPGA:
Employs Field-Programmable Gate Arrays (FPGAs) for real-time implementation of the compression algorithm. Utilizes Vivado High-Level Synthesis (HLS) to convert high-level algorithm descriptions into efficient hardware implementations. Parallel processing capabilities of FPGAs significantly reduce latency and enhance throughput.

Implementation:
The OEIC method is implemented and tested on the Arty Z7-20 development kit using Vivado HLS. The implementation involves the following steps:
Algorithm Development:
Develop the OEIC algorithm in C/C++ for high-level simulation and verification. Optimize the algorithm for FPGA implementation, focusing on resource utilization and processing speed.
High-Level Synthesis: Use Vivado HLS to convert the high-level algorithm into VHDL/Verilog code. Perform synthesis to generate the hardware description and optimize the design for the target FPGA.
Hardware Integration:
Integrate the synthesized design into the FPGA development environment. Test and validate the implementation on the Arty Z7-20 kit, ensuring correct functionality and performance.

RESULTS AND DISCUSSIONS

Table 1: Table for compressed and decompressed outputs for different medical images

Input image as JPEG format

JPEG Input image	Compressed image	Decompressed image
CT Scan Chest input image With Pixel value 1280 x 1234 	Pixel value 256 x 256 	Pixel value 1280 x 1234 
Ultrasound Kidney input image With Pixel value 816 x 614 	Pixel value 256 x 256 	Pixel value 816 x 614 
Microscopic Skin input image with Pixel value 750 x 354 	Pixel value 256 x 256 	Pixel value 750 x 354 

NOTE: Regarding CT scan chest image supporting data got from Government Hospital of Kanchipuram. Regarding ultrasound kidney image, microscopic skin image supporting data got from MEDLABS, GUDUVANCHERRY.

Performance Evaluation:

Evaluate the performance of the OEIC method in terms of compression ratio, image quality (PSNR). Compare the results with existing compression methods to demonstrate the advantages of the proposed approach.

Compression Ratio: Achieves higher compression ratios without noticeable loss of image quality with 5.4.

Image Quality: Maintains high Peak Signal-to-Noise Ratio (PSNR) as 68.75

Results obtained in vivado HLX environment

Software Simulation result for CT scan chest image

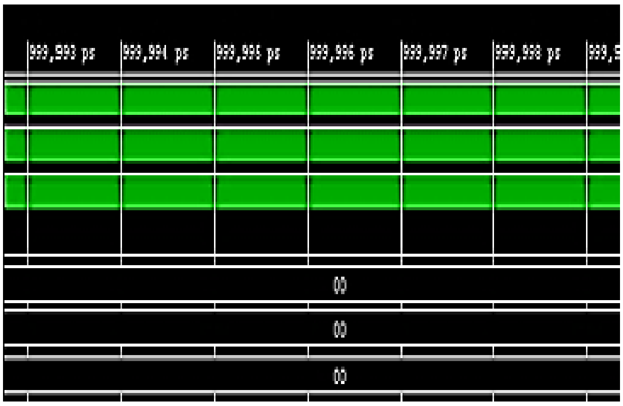


Figure 1 Simulation result using vivado for Arty z7 20kit

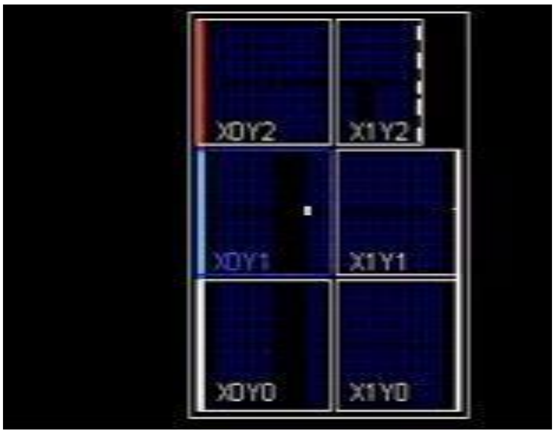


Figure 2 Synthesis result using vivado for Arty z7 20kit

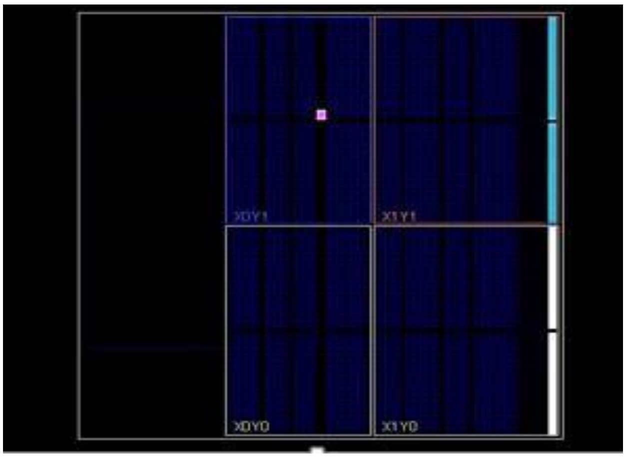


Figure 3 Implementation result using vivado for Arty z7 20 kit

Software Simulation result for ultrasound kidney image

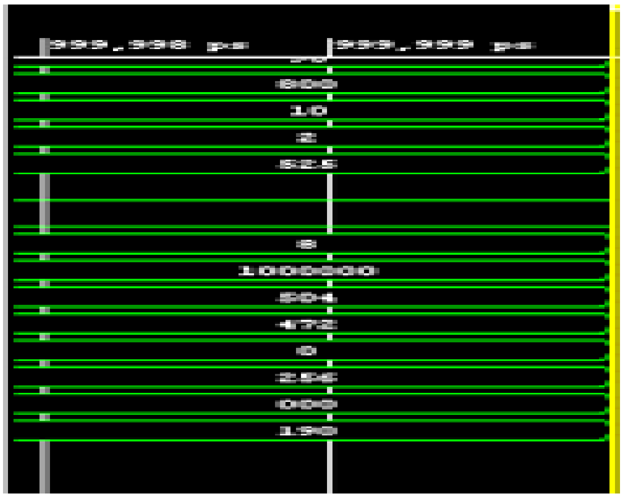


Figure 4 Simulation result using vivado for Arty z7 20kit

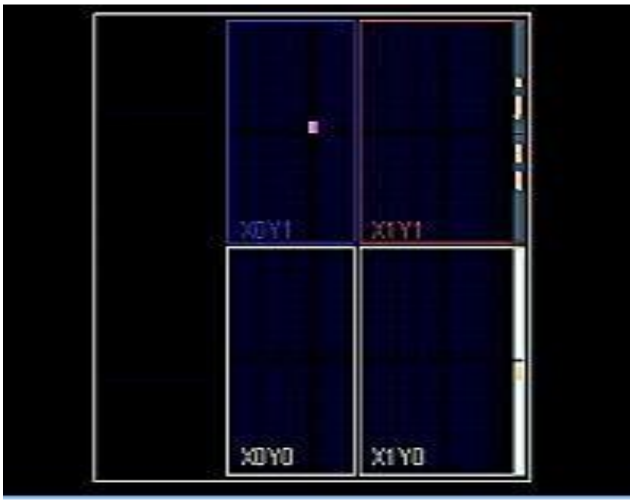


Figure 5 Synthesis result using vivado for Arty z7 20kit

Figure 6 Implementation result using vivado for Arty z7 20 kit

Software Simulation result for microscopic skin image

Figure 7 Simulation result using vivado for Arty z7 20kit

Figure 8 Synthesis result using vivado for Arty z7 20kit

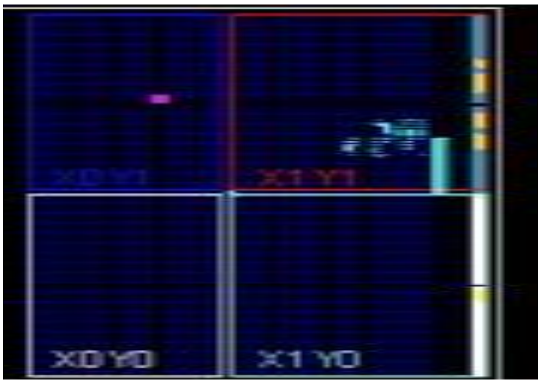


Figure 9 Implementation result using vivado for Arty z7 20 kit

Project summary

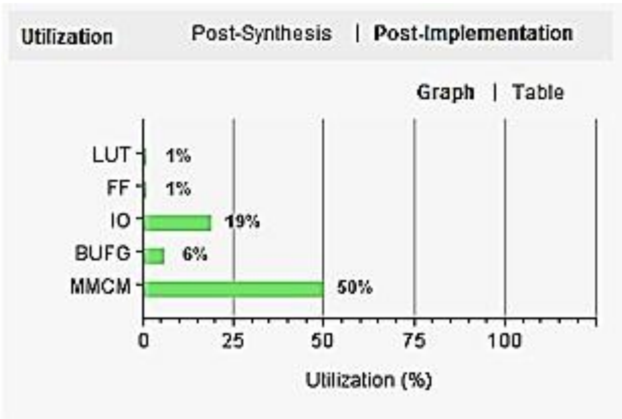


Figure 10 Project summary report using vivado for Arty z7 20 kit

Hardware Implementation of Arty z7 20t kit

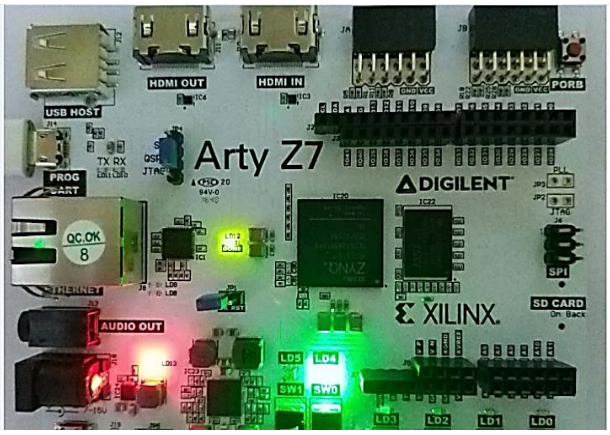


Figure 11 Hardware Implementation Result using Arty z7 20t kit.

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Disclosure Statement

No potential conflict of interest was reported by the authors.

CONCLUSION

The proposed Optimal Enhanced-Based Image Compression method offers a highly efficient solution for image compression, leveraging advanced algorithms and FPGA technology. The combination of hybrid transform coding, adaptive quantization, entropy coding, and optimized rate-distortion strategies results in superior compression performance. The FPGA implementation using Vivado HLS ensures real-time processing capabilities, making the OEIC method suitable for a wide range of applications, including medical imaging and digital media.

FUTURE WORK

Future research will focus on further optimizing the OEIC method for specific application requirements, exploring advanced machine learning techniques for adaptive compression, and extending the implementation to other FPGA platforms to enhance scalability and performance.

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