Investigation of DWT's Superiority Over DCT

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Abstract

The Discrete Wavelet Transform (DWT) algorithm is responsible for images' crucial role in education due to its increased efficiency over Discrete Cosine Transform (DCT). This superiority of DWT is evident through the algorithm's careful construction which allows it to repel blocking artifacts, a distortion that is common in DCT compressed images. In addition, DWT boasts higher scores on common technical compression algorithm metrics such as the compression ratio, mean square error, and peak signal-to-noise ratio. This indicates that DWT not only delivers a smaller sized image but also a better quality one in comparison to DCT, establishing DWT's technical dominance. This combined with images' incredible ramifications on modern-day education by conveying events, historical or current, through a visual medium showcases DWT's importance in the education field. This is because DWT allows images' to have a positive impact on society on the account of DWT's effectiveness in compressing images to be easily distributable. Furthermore, revealing how easily society can be drastically altered by a single algorithm thus illustrating computer professionals' responsibility to predict a private algorithm's effect on society and to respond appropriately to the prediction before it is released for public use.

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The modern-day world heavily relies on the lightweight of images as this enables the easy distribution of images, allowing for images' critical role in numerous aspects of society, such as education. Image compression algorithms such as Discrete Wavelet Transform and Discrete Cosine Transform achieve this marvel by condensing repeated elements in an image. While the Discrete Cosine Transform algorithm may be more influential, the Discrete Wavelet Transform algorithm is more efficient. The image compression algorithm, Discrete Wavelet

Transform (DWT), holds superiority over the Discrete Cosine Transform (DCT) algorithm with its faster encoding time and overall production of better quality images, enabling the use of images as a lightweight vessel of information and permitting images' beneficial role in education. This is highlighted by the Discrete Wavelet Transform algorithm's meticulous construction, the algorithm's ability to reduce the size of images tremendously while preserving image quality, and its expeditious encoding times. Although they are decades old, DWT and DCT were not some of the first algorithms but ultimately utilized the groundwork laid by predecessor algorithms such as the Huffman Coding algorithm.

Alternate Technology

The Huffman Coding algorithm preceded DWT and DCT, laying the foundation for them with its straightforward but effective method of compressing data. According to Gaurav Kumar (2015), an M.Tech scholar and author of a paper that compares various image compression algorithms, the algorithm operates by modifying the fixed bit representations of characters in a text into variable-length bit representations. Through this process, the length of the bit representations of the most used characters in a text will shrink, consequently compressing data by shrinking the total usage of bits. This is accomplished by reading each character in a text and keeping track of the frequency that these characters appear in the text. Subsequently, a list holds these characters from the most used in the text to the least. After, the algorithm fabricates a binary tree. A binary tree is a tree data structure that links other data structures (nodes) together in a manner that permits the timely retrieval of the desired node. The Huffman Coding algorithm constructs this binary tree by first linking the two least used characters with the sum of their frequencies, consequently appending them back into the list. This procedure recurs until every element transforms into a node and every node connects through the root node, the node that every node is a descendant of. Finally, a simple traversal down the binary tree is enough to supply every character in the text with a spatially efficient variable-length bit representation. Specifically, this happens by establishing if the desired node, the character needing to be encoded, is to the current node's left. If so, the bit zero is delineated; otherwise, the bit one. Then, this repeats until the algorithm discovers the desired node. To uncompress text, an analogous procedure is orchestrated, with the difference being that every right fork produces the bit one, and every left fork produces the bit zero. After that, Huffman Coding uses the bit zero to pad the bit representation to the targeted fixed length if the length of the representation is less than this fixed length. If the bit representation is bigger than this length, the algorithm eliminates the rightmost bit value until the appropriate length. While the Huffman Coding algorithm appears straightforward, analysis divulges that the algorithm performs surprisingly well on some of the most common compression efficiency metrics; the half-century-old algorithm has a fast compression speed (Kumar et al., 2015, p.26). However, the paper mentions that the Huffman Coding algorithm does poorly on the compression ratio test. The compression ratio is a simple equation frequently used to measure the usefulness of a compression algorithm by forming a ratio between the size of the original image and the size of the compressed image, demonstrating the extent to which the compression algorithm reduces the size of the original image with a greater quotient (Kumar et al., 2015, p.28). On the frequently used PSNR (peak signal to noise ratio) test, an evaluation of the image quality between the original image and the compressed image using the following equation: $PSNR = 10log10(Max_i^2/MSE)$, the Huffman Coding algorithm receives an undefined (Kumar et al., 2015, p.28). This occurs because, according to Kumar, the maximum pixel intensity value (Max_i^2) gets divided by the MSE (mean square error), another equation (see equation 1) that compares the pixels of the original and compressed image to evaluate the image quality degradation (Kumar et al., 2015, p.28).

Equation 1

Depicts the equation for Mean Square Error (MSE)

$$\mathrm{MSE} = \frac{1}{\mathrm{MN}} \sum_{i=0}^{M-1} \sum_{j=1}^{N-1} [\{x(i,j) - y(i,j)\}^{2}]$$

The paper states that the MSE is generally a lower number when there is less image quality loss, a higher number when there is more, and equals zero when there is no difference between the images, which is the case here. This arises because the Huffman Coding algorithm is a lossless form of compression, "the original image is similar to the decompressed image, but CR is low" (Kumar et al., 2015, p.21). This quote explains the lack of degradation in image quality for lossless compression algorithms, highlighting that this occurs at the expense of a lackluster difference between the sizes of the original image and the compressed image. This comes in stark contrast to DCT and DWT, both of which are lossy forms of compression that attempt to maximize the quality of an image while minimizing its size (Kumar et al., 2015, p.21).

Support

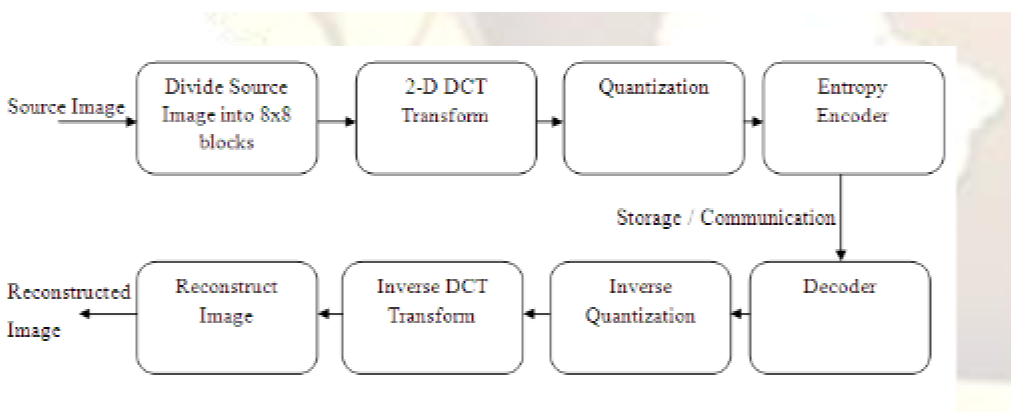
DWT's Meticulous Construction

DCT and DWT both strive to reduce an image's size while preserving its quality as much as possible. However, an investigation of the technical aspects of the algorithms verifies that DWT's meticulous construction allows it to be a more efficient algorithm than DCT. Discrete Cosine Transform compresses pictures through the use of cosine waves. Firstly, this is accomplished by transforming data in pictures, or pixels into cosine waves. Afterward, the frequencies of the waves are sorted in descending order. Next, Maneesha Gupta and Dr. Amit

Kumar Garg (2012) of the Maharishi Markandeshwar University, in a paper analyzing the DCT algorithm's inner workings as well as the efficiency of the algorithm, state that the high-frequency waves are removed "...based on allowable resolution loss." This means that the move is effective because the removal of high-frequency waves has a minimal effect on the resolution of an image but a significant effect on the size of an image. Ultimately, according to Irena Hwang (2021), a data reporter at ProPublica, the removal of elements in an image that contribute the least to a picture's visual fidelity is the main problem that lossy compression algorithms attempt to solve. The erasure of these high-frequency waves is achieved through quantization (Gupta & Garg, 2012, p.516). Quantization details that fewer bits are given to the unimportant waves while the lower frequency waves are given comparatively more bits, preserving the quality of critical chucks of the image but reducing the overall bit size of the image, see figure 1 for a block diagram showing quantization's role in DCT (Gupta & Garg, 2012, p.517).

Figure 1

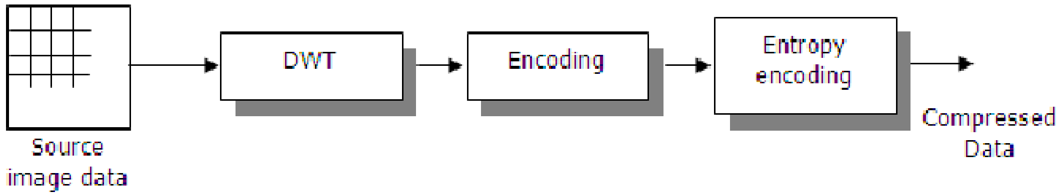
A block diagram of the processes that DCT undergoes



Discrete Wavelet Transform operates in a similar function, but instead of using cosine waves, wavelets are used, see figure 2 for a flowchart of how DWT works (Parmar, 2014, p.665).

Figure 2

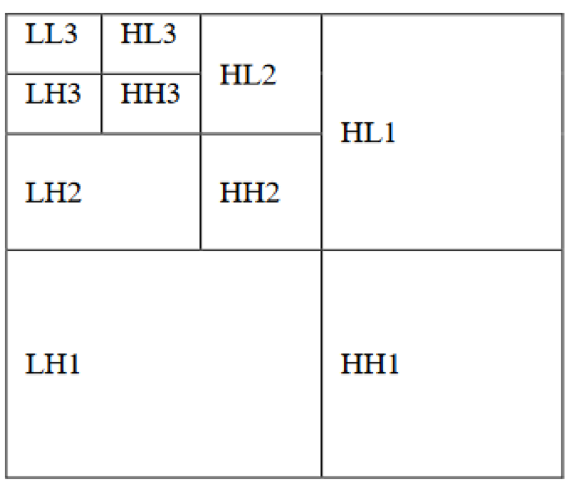
A flowchart depicting the processes DWT undergoes to produce a compressed image



According to Himanshu M. Parmar (2014) of the Sankalchand College of Engineering, the use of wavelets allows for multiresolution, a method of analyzing signals at "...different scales or resolution", refer to figure 3 for how DWT decomposes an image into multiple levels (Kumar et al., 2015, p.22).

Figure 3

A depiction of how DWT decomposes an image into multi-levels



Rajesh K. Yadav (2012) states that multiresolution allows for DWT compressed images to be "... especially suitable for applications where scalability and tolerable degradation are important". The utilization of this overall complex system allows for some out-of-the-gate benefits for DWT over DCT. One such benefit is that the use of wavelets allows for the elimination of blocking artifacts. This distortion occurs due to pixel blocks that are larger than normal, that plague DCT compressed images but can be avoided by DWT as for DCT, "... there is no need to block the input image and its basis functions have variable length…" (Parmar, 2014, p.666). Parmar further reveals that the usage of wavelets also "...facilitates progressive transmission of images." Ultimately, the design of the fundamentals of DWT gives some inherent advantages over DCT, but it also spawns merits in traditional image compression comparisons.

Compression Analysis Metric

PSNR, MSE, and CR are the traditional criteria used to analyze the performance of image compression algorithms. When it comes to an analysis using these methods, DWT still possesses a clear edge over DCT. An analysis of both algorithms using the compression ratio metric finds, according to Kumar (2015), that DWT has a higher ratio than DCT. This indicates that compared to DCT, DWT has done an effective job at reducing the size of the original image. Furthermore; Kumar brings to light that the mean square error of DWT is lower than that of DCT, revealing that through this metric, a DWT compressed image suffers little image quality degradation in comparison to a DCT compressed image. In addition, Kumar mentions that DWT has a higher peak signal-to-noise ratio value than DCT. The use of this function showcases that images compressed by DWT are of superior quality to images compressed by DCT. Finally, to conclude DWT's superiority over DCT, Kumar's inspection of their respective encoding times reveals that DCT takes longer to encode images than DWT. This divulges discrete wavelet transform's clear supremacy over discrete cosine transform as it edges out DCT in many principal metrics while taking a shorter time to encode an image. With its technological dominance over DCT, DWT carries the burden of image compression's pivotal position in permitting images' incredible impact on education.

Social Impact

Image compression algorithms have had and continue to have an influential impact in transforming images into featherweights that can be easily shared and distributed on the internet. Decades ago, images clogged the loading times of websites, requiring web developers to moderate their usage of images. With the advent of discrete cosine transform and discrete wave transform, images can now be freely used on websites with no restrictions due to the standardization of image compression. A professor at the Swiss Federal Institute of Technology Lausanne, Professor Touradj Ebrahimi, shares this same sentiment. Ebrahimi reveals that JPEG, an image format that relies upon the usage of DCT, was "...created to address a major problem in the digital age…we had to find a way to reduce the size of image files" (Pessina, 2014, para. 3). Irena Hwang also indicates the power of image compression by stating that JPEG "...can reduce image sizes between 5 and 100 times." JPEG's achievement of converting images to featherweights showcases that image compression has played a critical role in shrinking the size of images. As a result of this small weight achieved by image compression algorithms, with DWT looking to become a new standard in efficiency for this area, images were granted their current ability to play a noteworthy role in education.

Whereas before, the bulkiness of images restricted their ability to be distributed on the world wide web, image compression has now allowed pictures to become an educational tool used to teach people about current events and atrocities around the world. Jonathan Klein (2010), a co-founder of Getty Images, argues for this outlook in a TED Talk. In the presentation, Klein highlights a wide range of photos that have had an incredible impact on the world and therefore have played a prominent role in education. Klein details that a particular image that portrayed Earth from the perspective of an astronaut on the Moon, "...changed our view of the physical world" (Klein, 2010, 00:45). He further reveals that this image revolutionized the outlook that many had on our planet so much that a plethora of people hold the belief that this image kickstarted the environmental movement, a clear example of images' critical role in education. Klein digs deeper into images' vital role in educating about environmental issues by disclosing an image depicting murdered gorillas in the Congo. Klein reports that this image educated the rest of the world about this horror so much so that the incident "...sparked international outrage", further displaying images' prominent role in education (Klein, 2010, 1:22). He delivers more examples of photographs' importance in education by revealing images that illustrate the horrors of humanity throughout history and in the present. In his presentation, the co-founder of Getty Images displays an image of Princess Diana caressing an HIV/AIDS infected baby, stating that the Princess of Wales utilized the tremendous power of images to educate to destigmatize the facts that surrounded the hysteria about the transmission of HIV and AIDS. Klein also demonstrated this same notion by presenting an image consisting of two severely malnourished children. Regarding this image, he remarked the following: "So when we are confronted by a powerful image, we all have a choice: We can look away, or we can address the image." Clarifying this quote, Klein tells the audience that this photograph allowed the depicted Sudan famine to dominate the global conversation, accomplishing much good for the Sudan famine relief efforts and demonstrating images' unparalleled purpose in education. If photos were bulky, then their ability to be swiftly distributed would be impeded and consequently would prohibit the extent of their importance in education. Thankfully, this is not the case due to image compression algorithms such as DWT, as they permit images to be lightweight, subsequently allowing their prominent place in the education system. Thus, a rising algorithm like DWT has massive ramifications on the state of society as similar compression algorithms play and have played a staggering role in education.

Conclusion

While Discrete Cosine Transform and Discrete Wavelet Transform have both dramatically improved the distribution process of images, the DWT algorithm edges out in terms of efficiency. This rests upon the fact that DWT boasts a more meticulous infrastructure, allowing for perks such as the removal of blocking artifacts from its images. In addition, DWT outcompetes DCT in many of the benchmark metrics for compression algorithms. This includes the compression ratio, the mean square error, and the peak signal-to-noise ratio, revealing that DWT shrinks the size of images more than DCT while also outputting images of superior visual quality. With DWT's faster encoding time appended to its list of advantages, it is evident that DWT holds technical superiority over DCT, consequently granting images a principal beneficial role in the education sector by allowing them to serve as lightweight visual tools saturated with information about a particular topic. As a result of this conclusion, the pivotal role that computer professionals must serve as the harbinger of algorithms that may have a profuse, positive or negative, impact on society is revealed. Consequently, this portrays the vital responsibility of computer professionals to conduct a testing phase to provide the opportunity to predict a private algorithm's effect on the world to sufficiently judge if the algorithm will have a widespread negative impact on society, restricting the algorithm in such a case. As ultimately, DWT's positive impression on the education sector brings to light the powerful outcomes that a single algorithm can generate, but this also causes concerns about the negative aftermath that a single algorithm can generate.

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