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Efficient Energy Consumption DCT-Based Image Compression in Visual Sensor Network

Khamees Khalaf Hasan, Ibrahim Khalil Salih and Kamil Jadoaa Ali
Department of Electrical Engineering, Faculty of Engineering, University of Tikrit, Tikrit, Iraq

Abstract: For future wireless access technologies, the furthermost significant challenges will be the requirement to process and transmit a huge volume of image data wirelessly. One method to relieve this difficulty is by compression techniques to decrease the magnitude of transmitted image data over the wireless channel. Discrete Cosine Transform DCT utilized as a kernel transform coding of Joint Photographic Experts Group (JPEG) compression technique. DCT packing the image signal energy into few numbers of transformed coefficients associated with low frequencies. The high frequency coefficients may be discarded with little loss in image signal energy and that will not effect that much on the reconstructed image quality, since, the human eye doesn't sense the high frequency components. Using a modified version of JPEG according to the energy requirement of Visual Sensor Network VSN an adapted JPEG method is proposed. This involves the concept of processing only the low frequency portion of each block of the DCT coefficients of a given image. The compression algorithm in the proposed JPEG scheme minimizes the computational complexity and reduces the required energy consumption needed to transmit an image while it allows a trade-off between image distortion using Peak Signal to Noise Ratio PSNR metric and Compression Ratio CR. When the number of retained useful low frequency coefficient is 30% and less, the reconstructed images shows a noticeable degradation at all which can be used to counter severe hardware constraints of various wireless devices applications.

Key words: JPEG, discarding process, DCT, retained coefficients, VSN, CR

INTRODUCTION

Recently, a substantial portion of wireless data is comprised of images. Most of the VSN applications are centered towards harvesting image information from the physical environment, performing simple processing on the extracted data and transmitting it to remote locations as shown in Fig. 1 (Nasri *et al*., 2010).

Widespread use of mobile devices and wireless sensors require algorithms that can comply with the representation of the input data in a proper form for storage and transmission. One approach to overcome this problem is to eliminate redundant information from the

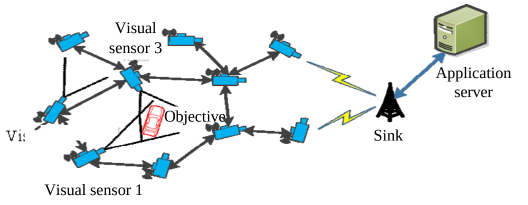

Fig. 1: Visual sensor network architecture (Nasri *et al*., 2010)

transmitted images or frames of data over the wireless channel through image compression techniques (Nasri *et al*., 2010). Typically, visual information needs to be compressed using some standards such as the (JPEG) or (JPEG2000). These algorithms need very complex hardware requirements. However, these efforts fall short of meeting real-time processing requirements. Using an adapted version of JPEG according to the energy requirement of VSN, a new method is proposed. This involves the concept of processing only the upper-left portion of each block of the DCT coefficients of a given image. This is followed by modifying the parameters on the computation time and communication energy. Nevertheless, JPEG has many restrictions using DCT, especially, at portable low bit-rate applications. The energy compaction property of DCT was used in (Taylor and Dey, 2001) but they investigated this idea in mobile wireless multimedia networks requirements. Chiasserini *et al.* (2002) implemented JPEG with integer DCT kernel as compression algorithm. The research did not certainly familiarize JPEG to the VSN energy requirement. Pekhteryev *et al.* (2005) studied only the transmission of JPEG images over the applied wireless

Corresponding Author: Khamees Khalaf Hasan, Department of Electrical Engineering, Faculty of Engineering, University of Tikrit, Tikrit, Iraq

communication standard IEEE 802.15.4 which outlines the Zigbee nodes. The idea of minimizing the processing and transmission energy when executing JPEG in VSN was explored by Mammeri *et al*. (2008a, b) where the DCT compaction used a slice of each block of DCT coefficients, the selected coefficients slice is triangular. Mammeri *et al*. (2008a, b) used the square type of the selected coefficients portion but they do not consider how the values of the coefficients are selected. Mammeri *et al*. (2008a, b) proposed two methods for selecting this value in the case of triangular selection. The squared approach was not investigated. Both squared and triangular type of the DCT coefficients portion to be processed by Makkaoui *et al*. (2010a, b) but did not propose any method for selecting the size, (i.e., the number of DCT coefficients). Fast DCT algorithms as well as zonal techniques have been intensively studied in the literature (Loeffler *et al*., 1989; Feig and Winograd, 1992; Bracamonte *et al*., 1996; Liang and Tran, 2001; Taylor and Dey, 2001; Jeong *et al*., 2004; Ferrigno *et al*., 2005; Hsieh and Zonal, 2005) there is no work of them that combines both squared and triangular approaches, especially in the wireless networks context. In this study, the proposed algorithm for handling this constraint problem consists of adapting JPEG to the energy requirement of VSNs. This is done by processing only a portion of each block of DCT coefficients of the captured image using the effects of selecting the size (the number of low frequency DCT coefficients) of the portion to be processed on other performance metrics like the energy consumption using the discarding process as an alternative of the quantization process of high frequency components in traditional JPEG.

MATERIALS AND METHODS

Through that the image adjacent pixels are highly correlated, these unnecessary details can be rejected by finding a less correlated representation of the image using transform coding. The very stunning and public transform-based image processing and compression methods such as JPEG using DCT (Loeffler *et al*., 1989). A DCT encoder transforms the picture blocks and converts the signals into frequency components (Feig and Winograd, 1992). The DCT has a robust energy compaction and brilliant decorrelation property (Bracamonte *et al*., 1996; Liang and Tran, 2001). Most of the signal information tends to be concentrated in a few low-frequency components as shown in Fig. 2. The low frequency components remains, so that can be used in the reconstruction process (decompression).

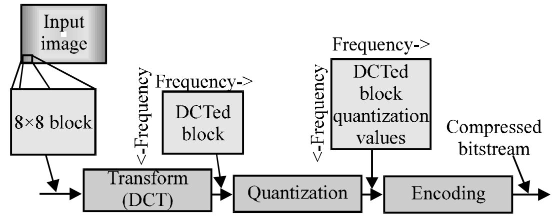

Fig. 2: Energy compaction property of DCT blocks Chew *et al*., 2008)

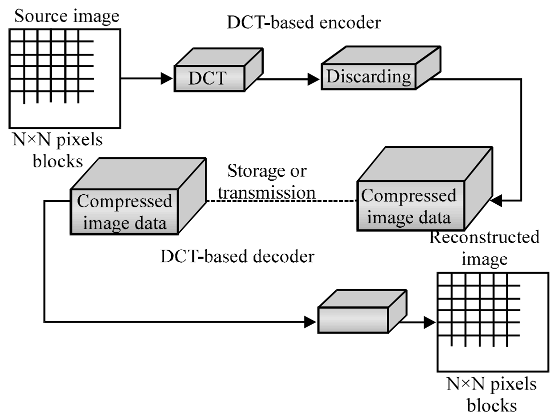

Fig. 3: Proposed DCT compression system

Since, the human eye will not notice or senses the high frequency components in the image, so, this gives the DCT an advantage of discarding the redundant data without affecting that much on the image. The less important (high) frequency components are discarded from the image in quantization process of high frequency components, hence, the use of lossy JPEG method for compression as shown in Fig. 2. Referring to JPEG system, discarding process as an alternative of the quantization process of high frequency components in the proposed adaptive JPEG method as shown in Fig. 3 which illustrate the main stages of DCT algorithm that proposed in this research. At the receiving point these discarded DCT coefficient are inverse transformed using the inverse DCT to reconstruct the image. JPEG image compression scheme based on the DCT are very popular but this transform is computationally intensive and hence is energy consuming. Unfortunately, the resource limitation of sensor nodes in VSNs in terms of memory or processor speed makes most of the compression algorithms inapplicable. The proposal presents a methodology to reduce the energy consumption of VSN node. This methodology allows a trade-off between energy consumption and image distortion. Actually, a number of applications have a preference for saving computation energy over image quality for remote VSN application

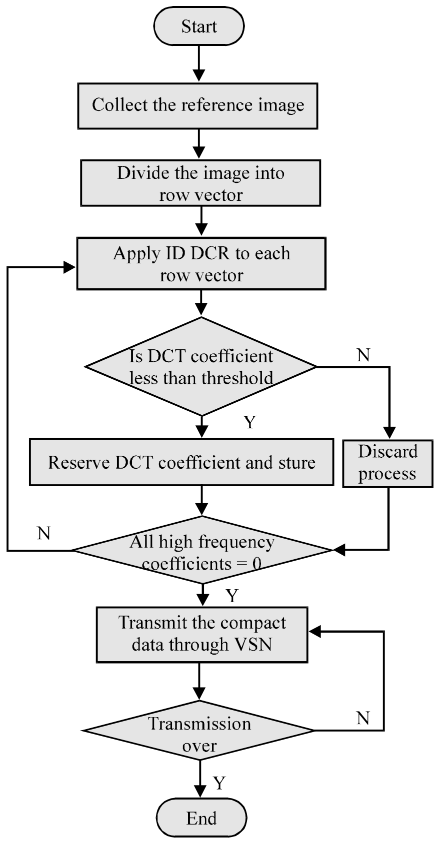

Fig. 4: Adapted JPEG image compression algorithm for the VSN

while other applications focus on high quality feature of images rather than the amount of energy consumed (Akyildiz *et al*., 2007; Wu and Abouzeid, 2005; Srisooksai *et al*., 2012; Hasan *et al*., 2014).

Even though the DCT process is unable to compress the input images, it is the computation-intensive principal segment of the DCT-based image compression system that promotes energy consumption. Therefore, this study focuses on the DCT transform phase in order to decrease energy consumption. Thus, decreasing the amount of transmitted data will reduce communication energy and hence, expand the general wireless network lifetime. From the block diagram shown in Fig. 4 of the suggested JPEG image compression algorithm for the VSN requirements, the image first transformed into DCT coefficients where the low frequency components kept, so, these coefficients can be used in the reconstructing process and the high components are discarded, then these coefficients are stored or transmitted in DCT coding form. The proposed DCT system used in this study uses the discarding theory instead of the quantization as shown in Fig. 4.

The proposed system consists of five main stages, firstly, the encoding process of the input captured image by dividing the original image into two fields. Then each line in the field is divided into blocks of the same length. Each block is considered as a row vector. 1D DCT is applied to transform each row vector from spatial domain to frequency domain with the same dimension to be represented in a more compact form. The few low frequency coefficients represent the DCT packing of the image energy where the high frequency coefficient can be discarded with little loss in energy, the discarded coefficients are replaced by zero coefficients.

In the proposed system, the applied test images of size (256×256) with 256 gray levels, each line in the images is divided into two blocks. Each block is considered as a row vector of 128 pixels. 1D DCT is applied to convert each vector of pixels into a vector of 128 transformed coefficients. 1D DCT packing the energy into few numbers of transformed coefficients associated with low frequencies, the high frequency coefficients are discarded and replaced by zero coefficients.

In this system, we separate the image using DCT firstly into two blocks of (256×128) dimension, then we obtain the coefficients in the same dimension from column (1-128) in the first block and from column (129-256) in the second block. The energy compaction is in the first, little columns, so, we will delete the column that contain the very high frequency coefficients and will not transmit them. These important coefficients will feed into inverse DCT system to get the advantage of the combination with the transformed coefficients. Then most of the high frequency component were deleted in a sequence of steps testing the system performance while increasing the compression ratio as trade off the distortion measure PSNR.

RESULTS AND DISCUSSION

In the proposed DCT system using discarding theory of high frequency components that has very low coefficient values in the transformed image, three test images with different contains and details were used to evaluate the systems performance: langair image, bridge image and flowers image. Two performance measurements have been employed, namely the objective and subjective. The most widely measurement used for the objective quality image processing are the Mean Square Error (MSE) and Peak Signal to Noise Ratio (PSNR) and this is measured in dBs:

$$MSE = \frac{1}{N}\sum_{i=1}^{N}(x_i - y_i)^2 \quad (1)$$

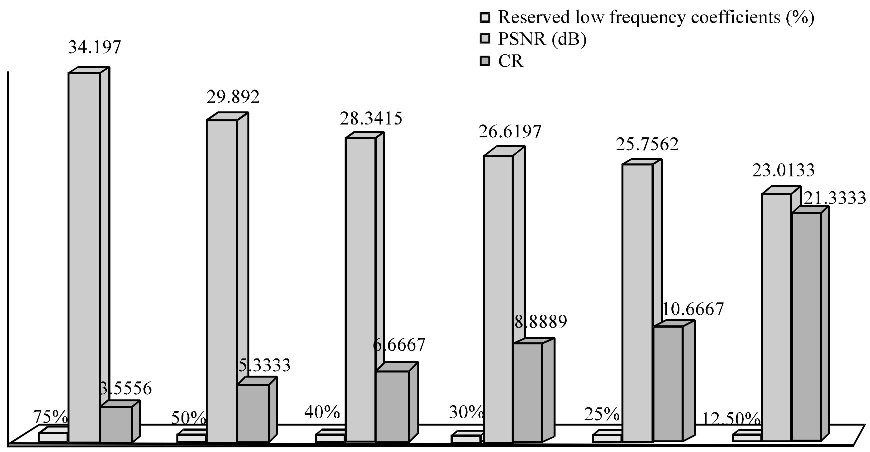

Fig. 5: CR and PSNR results of image “Langair”

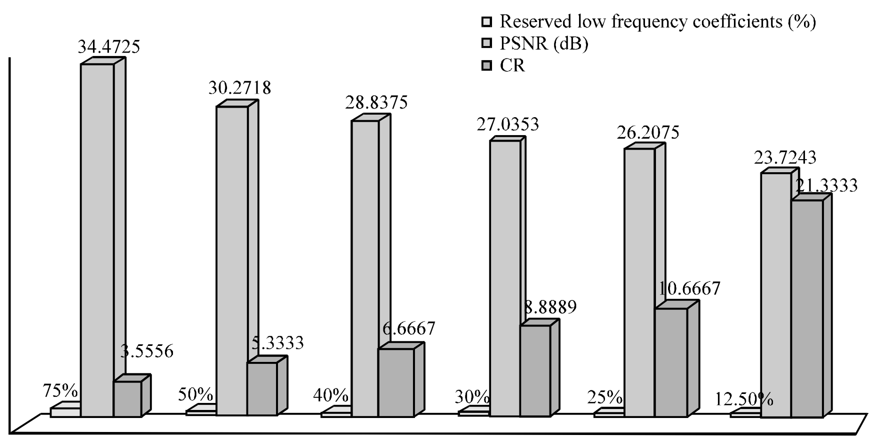

Fig. 6: CR and PSNR results of image “Bridge”

$$\text{PSNR} = 10\log_{10}\frac{L^2}{\text{MSE}} \quad (2)$$

Where:

N = The number of pixels in the image
x_i and y_i = The ith pixel in the original and reconstructed image signals, respectively
L = The dynamic range of the pixel (for 8 bits per pixel grayscale image L is equal to 255)

At times compression is as an alternative measured by asserting the bit rate achieved by compression in bpp (bits per pixel) and is defined by:

$$\text{BR} = \frac{\text{Original image size in bit}}{\text{No of pixels of the image}} \quad (3)$$

By applying the MATLAB program on these pictures this will yields to results showing the PSNR, Mean Square Error (MSE), CR and Bit Rate (BR). All these objective measurements plus the reconstructed image show how much the compression will effect on the image quality. Table 1-3 and Fig. 5-7 shows the values of (the objective

Table 1: Objective measurement of image “Langair”

Reserved coefficients (%)	PSNR (dB)	MSE	CR	BR (bpp)
75	34.4725	23.21840	3.55560	2.2500
50	29.8920	61.08010	5.33330	1.5000
40	28.8375	84.98200	6.66670	1.2000
30	27.0353	128.6923	8.88890	0.9000
25	26.2075	155.7158	10.6667	0.7500
12.5	23.7243	275.8369	21.3333	0.3750

Table 2: Objective measurement of image “Bridge”

Reserved coefficients (%)	PSNR (dB)	MSE	CR	BR (bpp)
75	34.1970	24.73880	3.55560	2.2500
50	30.2718	66.66160	5.33330	1.5000
40	28.3415	95.26400	6.66670	1.2000
30	26.6197	141.6149	8.88890	0.9000
25	25.7562	172.7656	10.6667	0.7500
12.5	23.0133	324.9001	21.3333	0.3750

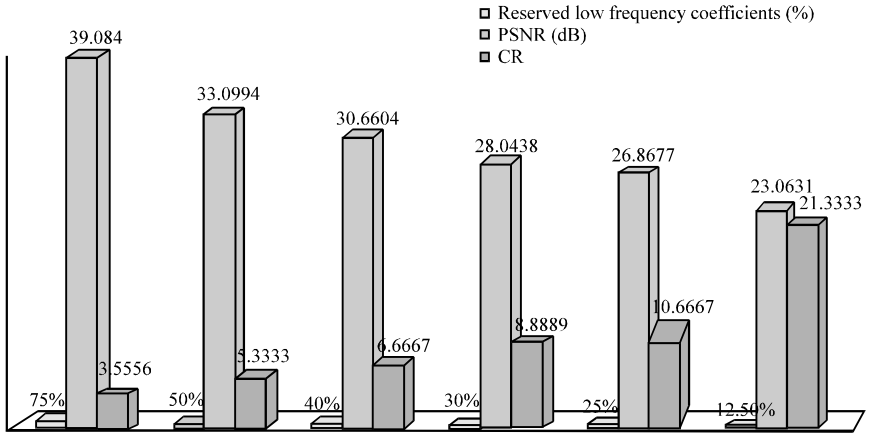

Fig. 7: CR and PSNR results of image "flower"

Table 3: Objective measurement of image "flower"

Reserved coefficients (%)	PSNR (dB)	MSE	CR	BR (bpp)
75	39.0840	24.7388	3.5556	2.2500
50	33.0994	66.6616	5.3333	1.5000
40	30.6604	95.2640	6.6667	1.2000
30	28.0438	141.6149	8.8889	0.9000
25	26.8677	172.7656	10.6667	0.7500
12.5	23.0631	324.9001	21.3333	0.3750

measurement) of each test image used in the system with different selected numbers of retained low frequency DCT coefficients as these coefficients decreases the compression ratio increases but with trade off the image quality of the reconstructed one by monitoring the PSNR decreases with noticeable degradation in image quality especially at the edges. Generally, when the bit rate decreases at low bit rate transmission of the image, the PSNR will decreases and the quality will be corrupted by smearing in the edges.

Figure 8-10b-g show the reconstructed images using (75, 50, 40, 30, 25 and 12.5%) low frequency coefficients, respectively. When the number of retained coefficient is 64 at bit rate 1.5 bpp, the reconstructed images shows a noticeable degradation at all. When the retained coefficient is taken to be (32 or 16) the reconstructed images show a noticeable smearing specially in the edges.

A comparison between the three reconstructed images using (75, 50, 40, 30, 25 and 12.5%) low frequency coefficients, respectively is shown in Fig. 11.

In order to evaluate the welfares of our proposal, we established a simplified energy consumption model for JPEG image transmission scheme. In this study, we offered an adaptive JPEG image compression model for VSNs based in DCT transmission and decomposition to achieve the energy conservation. According to the VSN constraints, this proposal is evidently relaxed to implement, allowing independent and self-adaptive performance of VSN sensor nodes and providing a compromise amongst dissipated energy and received image quality over the VSN. Image data is usually transmitted in further than one data packet. Once, captured image raw data is encoded (applying 1D DCT) and packetized into different priorities (75, 50, 40, 30, 25 and 12.5%), the data packets are then ready to be sent. The source sensor transmits the data packets beginning by those with the maximum priority, then continues with those of the next minor priority and so on continuing in the same way. This selection is driven by the constraint energy in the context of VSN. The utmost important parameters are PSNR and CR. These parameters will be tested during the compression process to make the decision to choice the optimal VSN technique according to the supply battery's state of charge. Succeeding priorities are only forwarded, if VSN node's supply battery level is above the lowest threshold. For instance, raw data of the "flower" captured image is encoded as shown in Fig. 12, if an energy level (a) near maximum threshold, a VSN node adopts a scheme which will increase the probability of forwarding packets to (75%) causing the lowest compression level is applied at 3.5556 with higher bit rate transmission (2.2500 bit per pixel). Such a policy will promote the reconstructed image quality to 39.0840 dB PSNR instead of energy savings. In opposition to what has beenstated, captured image packetized into lowest probability of (12.5%) low frequency DCT coefficients, if an energy level (a) near minimum threshold 0 at highest compression level 21.3333 and lower bit rate transmission (0.3750 bit per pixel). This will promote energy savings instead of a higher resolution of the final reconstructed image at 23.0631 dB PSNR. This choice will depend on the application in which the VSN is involved and the predictable usage of the extracted images (Akyildiz *et al*., 2002).

In this study because the decision performed by a VSN node is completed independently of the available energy in the other VSN nodes, our suggested transmission system is competent as open loop which offerings excessive adaptation to all kinds of routing arrangement and its modeling and execution are very simple.

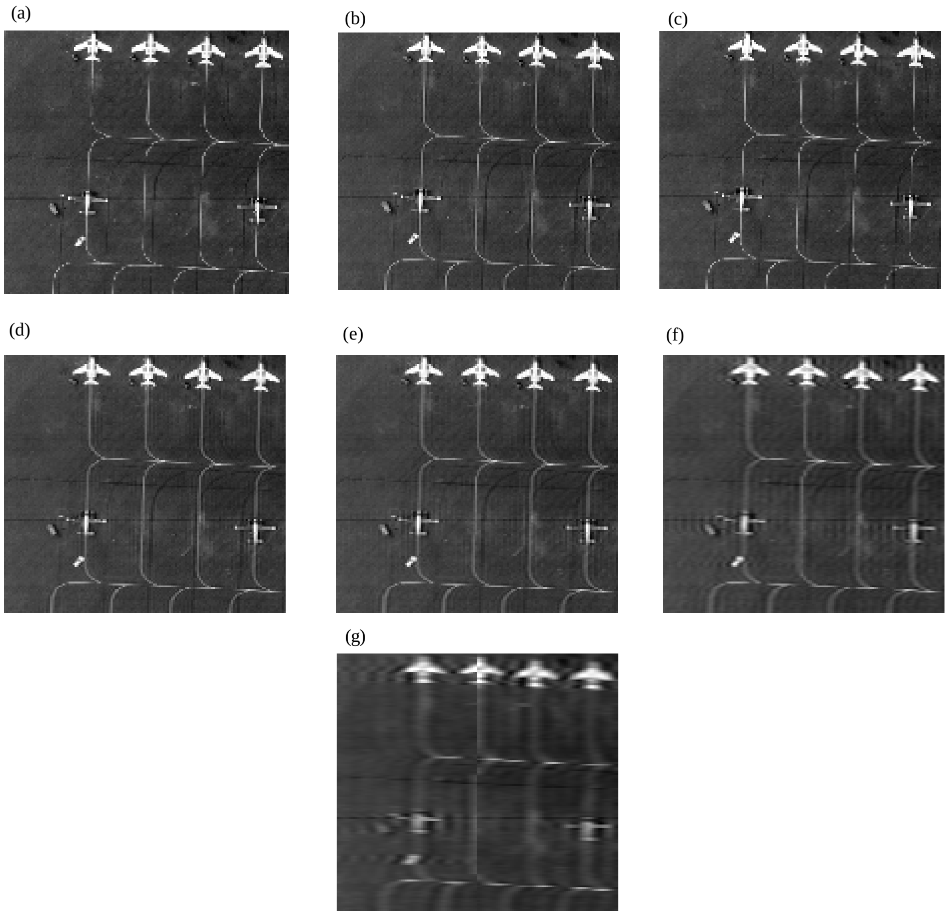

Fig. 8: a) Original image; b) Reconstructed image (75%); c) Reconstructed image (50%); d) Reconstructed image (40%); e) Reconstructed image (30%); f) Reconstructed image (25%) and g) Reconstructed image (12.5%)

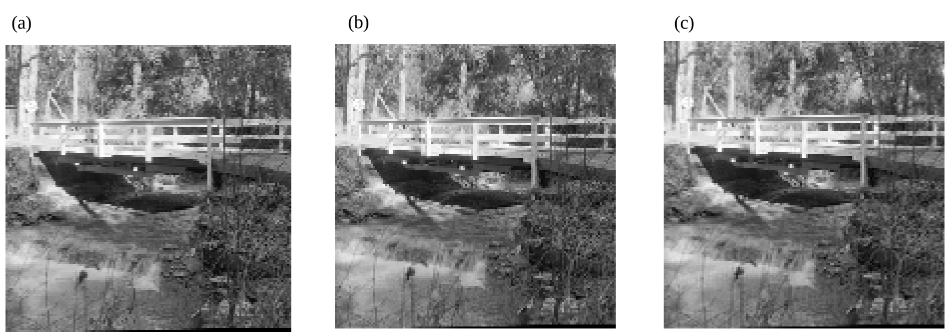

Fig. 9: Continue

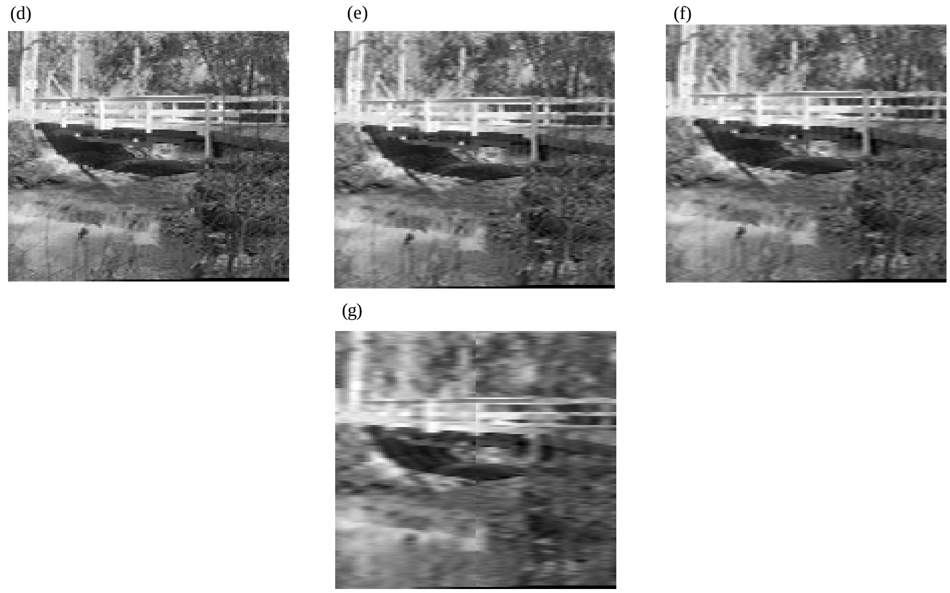

Fig. 9: a) Original image; b) Reconstructed image (75%); c) Reconstructed image (50%); d) Reconstructed image (40%); e) Reconstructed image (30%); f) Reconstructed image (25%) and g) Reconstructed image (12.5%)

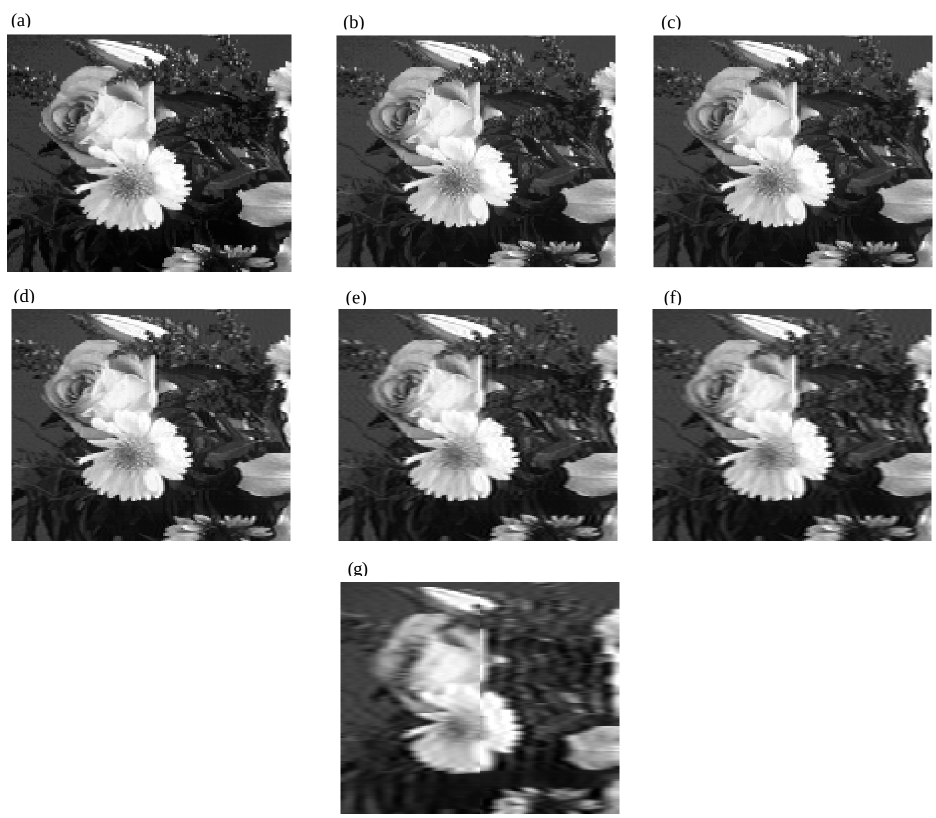

Fig. 10: a) Original image; b) Reconstructed image (75%); c) Reconstructed image (50%); d) Reconstructed image (40%); e) Reconstructed image (30%); f) Reconstructed image (25%) and g) Reconstructed image (12.5%)

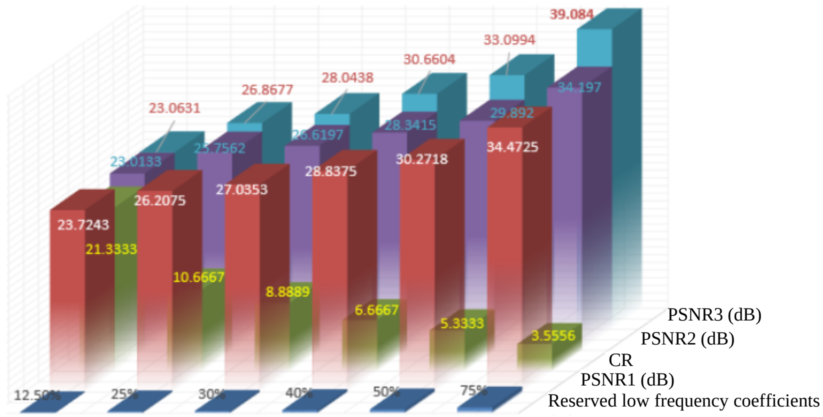

Fig. 11: A comparison between the three reconstructed images results

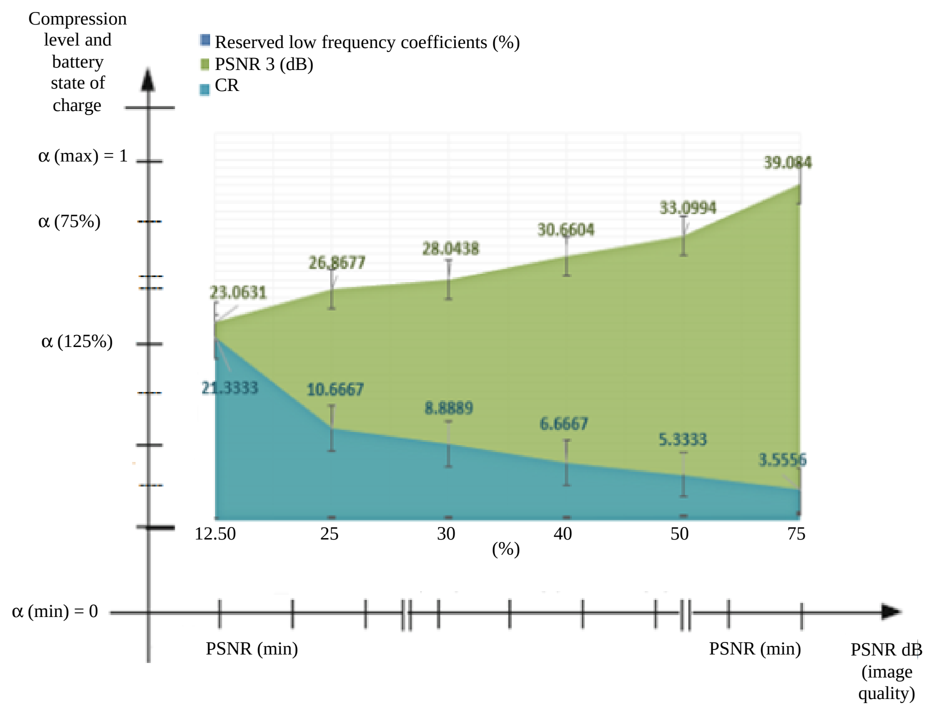

Fig. 12: VSN technique constraints policy based on PSNR and CR priorities process-based selection

CONCLUSION

This study has summarized a simple coding and effective energy depletion image compression system, i.e., discarding theory in VSNs. This approach reduces supply battery's energy consumption necessities meaningfully while retaining all the advantages achieved through modest adaptations to the JPEG Software. Furthermore, the discarding process of high frequency DCT coefficients provides a tradeoff between CR and image quality using DCT by segmenting each image line into vectors may result in blocking artifacts. These artifacts are perceptually annoying and become prominent in the reconstructed images at very low bit-rates. In this research, DCT based compression is investigated in the context of VSN at the sensor node. Nevertheless with less bits to transmit, this proposed technique will prolong the life of such networks and reduces supply battery's energy consumption.

RECOMMENDATIONS

In future research, closed loop plans will be explored to improve our proposal. A simulation will be delivered to provide more comprehensive and real results. Distributed and local compression algorithms will be considered to be combined in our proposal investigating their performances and their viability to be assimilated in a real wireless VSNs.

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