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Fast transmission of image, reduction of energy consumption and lifetime extension in wireless cameras networks

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In this paper, a fast image processing was proposed. It ensures energy efficiency and the extension of both the lifetime and the proper functioning of the network. It is a filtered zonal discrete cosine transform that allows and optimizes an effective adjustment of the trade-off between power consumption and image distortion. This is a remarkable energy saving method, in this kind of networks. It is applied throughout the chain of transmission and decompression of the image. It makes it possible to integrate a fast and a filtered zonal discrete cosine transform. This proposal dramatically improves the indicated method. The insertion of the frequency filters in this chain has greatly reduced the coefficients to be calculated and to be coded in each block. This new method ensures the fast transfer of images, decreases more the energy consumption of sensors and maintains a long network lifetime. This proposal seems to us very satisfactory as shown by the experimental results provided here.

Key words: Energy saving, fast zonal discrete cosine transform, filtered fast zonal discrete cosine transform, image compression, wireless vision sensors network, zonal coding.

INTRODUCTION

The development in sensor technology has allowed the design of sensor networks. These sensors are not as reliable or as accurate as their expensive macro sensor counterparts, but their size and cost enable applications to network hundreds or thousands of these sensors in order to achieve high quality, fault tolerant sensing networks. Reliable environment monitoring is important in a variety of commercial and military applications. The uses of these sensors are multiplying more and more, because they are inexpensive and their sizes are small.

But, the limitation of energy reserve and memory capacity in each node of any wireless network, generate several problems such as the reduction of the lifetime (Yong et al., 2016; Cristian, 2009), of the efficiency in network operations (Angelakis et al., 2014; He et al., 2017) and of energy saving (Eriksson et al., 2016; Huaying et al., 2018). In addition, this makes most of the algorithms of the embedded treatment unusable after a short time. Energy efficiency in image processing imposes to minimize any kind of operation on the mass of data used.

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Indeed, if a black and white image, of standard size 512 × 512 pixels, is coded on 8 bits per pixel, it generates 256 kb in uncompressed form. This becomes three times more important for a color image. The advantage of compression is obvious. Because of their low mass of data, compressed images take less time to be transmitted on the same channel (Shoaib and Alshebeili, 2012; Makkaoui et al., 2010; Loeffler et al., 1989; Feig and Winograd, 1992). Therefore, they require less energy. They only need a very small bandwidth to reach their destination. In general, there are two main compression algorithms. The first is lossless or reversible. It guarantees the perfect reconstruction of the images. But, the second algorithm is with loss or irreversible. It modifies more or less the value of the pixels (Shoaib and Alshebeili, 2012; Makkaoui et al., 2010; Loeffler et al., 1989; Feig and Winograd, 1992; Bracamonte et al., 1996; Liang and Tran, 2001; Taylor and Dey, 2001; Akyildiz et al., 2007; Jeong et al., 2004; Petracca et al., 2009; Ferrigno et al., 2005; Hsieh, 2005; Heyne et al., 2006; Puri et al., 2006; Sikka et al., 2004; Wark et al., 2007; Han et al., 2012; Ehsan and Hamdaoui, 2012; Heizelman et al., 2000; Jin et al., 2007; Wheeler and Pearlman, 2000; Wang et al., 2008). The lossless compression makes it possible to exploit the redundancies of the signal. But, it does not allow optimal compression rates. Since the image end user uses only the relevant information, lossy compression is often preferred. This algorithm makes it possible to achieve very high compression ratios. They depend on the quality level of the accepted information relative to the initial image and on the type of the adopted compression. The aim of image compression in the context of wireless cameras networks (WCN), is therefore to reduce the initial size of data in each node. This allows fewer packages to be sent via any WCN. This operation increases the lifetime of any vision sensor. This is justified by the estimated energy efficiency in it. This new representation will be decoded by a decompression procedure to reconstruct the image in the analysis station. This paper improves this operation. But, we do not work on communication protocol like that done by Heizelman model (Heizelman et al., 2000), where they used a LEACH, a clustering-based routing protocol that minimizes global energy usage by distributing the network load to all the nodes at different points in time. In each compressed image, we reduce the information redundancies. We desire to optimize as possible the relevant information in each compressed image to obtain high quality results. Large energy gains and a greater network lifetime can be achieved by this process, thereby requiring much less data to be transmitted to the base station. There is no work, to the best of our knowledge that uses this new method especially in WCN. In this operation, the FZ_DCT algorithm (Makkaoui et al., 2010), some image filters and the mean square error (MSE) were used. This is calculated by the following Formula 1.

$$MSE^2 = \frac{1}{N \times M} \sum_{i=1}^{N} \sum_{j=1}^{M} |x_{rec}[i,j] - x[i,j]|^2$$

PROPOSED METHOD

Principle

The principle of FFZ_DCT a Filtered Fast Zonal Discrete Cosine Transform (Figure 1) is very exciting by its easy computation and its remarkable importance. The fast LLM-DCT (Loeffler et al., 1989) and the zonal-DCT (Makkaoui et al., 2010) were taken as the starting points for our proposal. The corresponding algorithms (Makkaoui et al., 2010) were used with their complexity. Therefore, we have developed the FZ_DCT based image compression by computing the following coefficients:

$$C_{ij} = \frac{1}{4} K_i K_j \sum_{n=0}^{7} \sum_{m=0}^{7} p_{nm} \cos\left[\frac{(2n+1)i\pi}{16}\right] \cos\left[\frac{(2m+1)j\pi}{16}\right]$$

where $K_0 = K_0 = \left(\frac{1}{\sqrt{2}}\right)$, $K_{i \neq 0} = K_{j \neq 0} = 1$ and

$$p_{nm} = \frac{1}{4} \sum_{i=0}^{7} \sum_{j=0}^{7} K_i K_j C_{ij} \cos\left[\frac{(2n+1)i\pi}{16}\right] \cos\left[\frac{(2m+1)j\pi}{16}\right]$$

Whatever the size of the image, there are only 32 cosines involved in the coefficients calculation of the FZ_DCT. The previous double sum can be expressed in the matrix form (CPC^T) where P is the 8×8 matrix of the pixels and the elements of C are expressed in the form as follows:

$$C_{ij} = \frac{1}{2} \cos\left[\frac{(2j+1)i\pi}{16}\right]$$

This proposal consists to filter these coefficients. Only, the relevant coefficients of the upper left part of the image block will be coded according to their importance. In fact, the weakest coefficients can be reduced to zero. This reduces considerably the number of coefficients to be computed and to be coded in each block. This reduction may be sometimes more than 50%. An important energy saving is thus achieved throughout the chain of transmission and decompression.

In Figure 2, we show where each of the two approaches Fast Zonal DCT and Filtered Fast Zonal DCT, react in the compression chain. They are indicated first by FZ_DCT (1) and second by FFZ_DCT (2).

The image is considered to be spread over a rectangle. Filters have been inserted into the chosen area of the image as shown in Figure 3. They depend on the distance and on the size of the upper left corner of this image. This was by adding a frequency filters to this upper left area, each one according to a distance x which corresponds to the position of the coefficient DC(i,j) with respect to DC(0,0). These filters are thresholds F_x. Each one is used in each line vector (v) of a compressed image. If there is at least one component of this vector which is in the interval $[-F_x, F_x]$ then the components of (v) remain unchanged, otherwise all these components will be reset. The indicated filter F_x is defined by the indicated distance x and the cycle y chosen by the experiment as it appears in the following formula:

Filter x or $F_x = 2 x+y-1$

where $x \in \{1,2,.....,X-1\}$ and $y \in N$
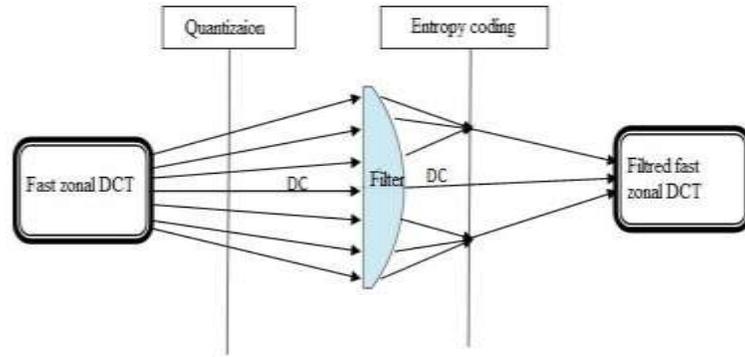
Figure 1. Principle of Filtered Fast Zonal DCT.
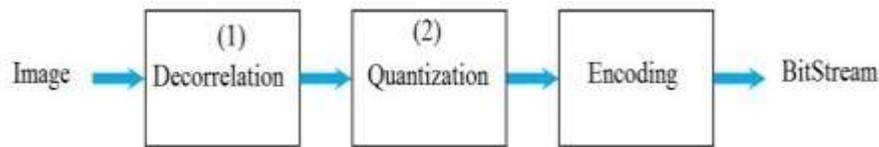
Figure 2. Activity phases of the both approaches.
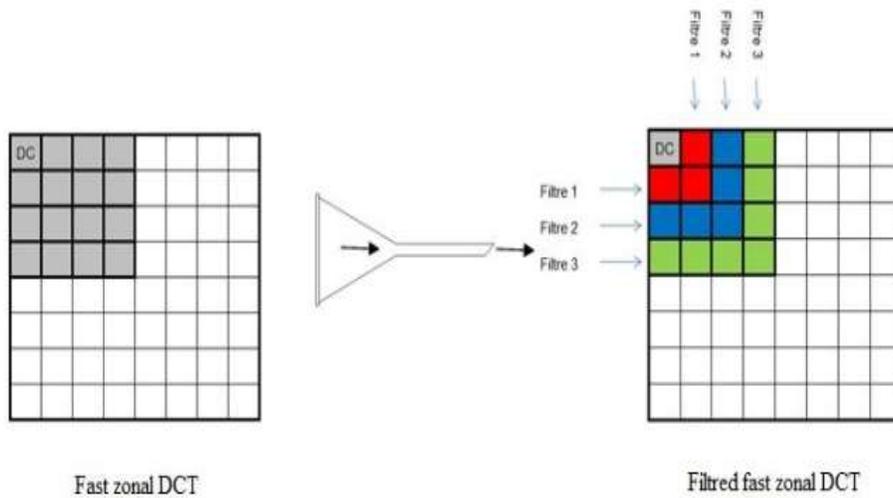
Figure 3. Filter effect on the Fast Zonal DCT.

With our new approach, we proceed as follows:

(1) In the quantization phase, we focus on the area chosen by the FZ_DCT algorithm (Makkaoui et al., 2010).
(2) We decrease with the chosen frequency filters, the number of coefficients. This is done by adding the indicted filters to the upper left area of the image. It depends on the coefficient position DC(i, j) defined with respect to DC(0,0).
(3) We evaluate and compare the results provided by each Classic DCT, FZ_DCT and FFZ_DCT methods. Indeed, the corresponding energy gain, MSE rate and image quality are calculated and compared as indicated subsequently.

This process is different to the algorithm of FZ_DCT. The FZ_DCT only affects the decorrelation phase. However, the new approach also affects the quantization phase. This is where we can see the effect of low-influence coefficients on image corruption. It is related to the large reduction in the number of bits transmitted by any WSN. Our principle is to minimize the cost of transmission and to increase the quality of the image. The cost here represents the energy consumption related first to the number of transmitted bits of a compressed image and second to the complexity of the multiplexing scheme during data decompression. The quality on the other hand, depends on the reduction of the interference during image
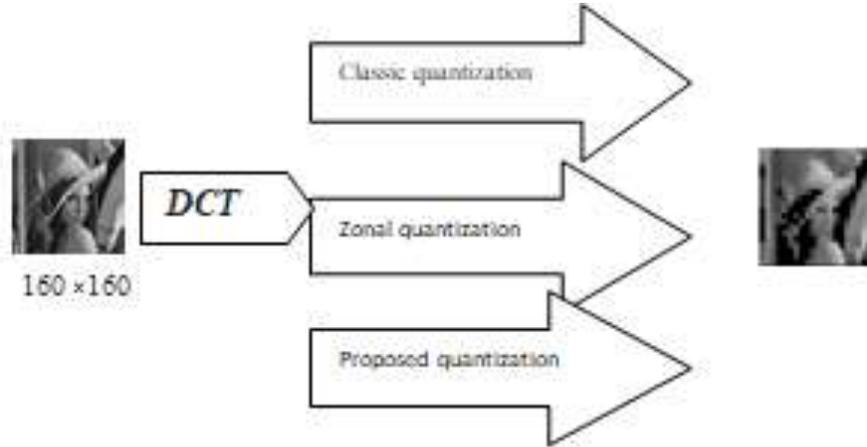
Figure 4. Image resolution after quantization in the three methods.

reconstitution.

Quantization phase

In this experiment, a source code [3] developed under Matlab software has been used. It allows the execution of all the steps of the compression chain. It has been modified to meet the challenges of our new approach. After the quantization phase, the code was divided into three parts (Figure 4). The first is to estimate the effect of Classic DCT or Conventional DCT that does not change anything at all. The second is to simulate the FZ_DCT [2] by replacing the coefficients of the 8×8 pixels matrix of the image with zeros except the upper left block N×N. And the last part is to simulate the FFZ_DCT our proposed method. It has been used in thresholds F_x (filters = N-1) in each line vector (v) of the upper left block N×N. Its transpose corresponds to a column vector (v^T), when at least one number is in the range [-F_x, F_x]. Then the numbers remain immutable. Otherwise, all digits will be replaced by zeros. This quantification with filtering does not alter the quality of the image (Figure 4). But it has greatly reduced the number of coefficients to be treated.

RESULTS AND DISCUSSION

The proposal's effect on the quality

The curves on the following figure show that the proposed FFZ_DCT offers better results than the others methods. The corresponding curve is green. Precisely, the upper curve indicates that more zeros appear in the blocks of the image to be compressed and more again if the square size decreases (Figure 5).

In application of Zonal_DCT and FFZ_DCT, we compute p_{nm} coefficients. Therefore, the decompressed image reconstruction has the following results (Table 1). Our proposal preserves more necessary details and more resolution for different square sizes (S) than Zonal DCT method. Indeed, the image quality is the clearest.

In addition, the image quality was analyzed by another

processing. Indeed, the Structural Similarity Index Measure, Metric based on the local structural analysis of the image was calculated. This metric is known as SSIM (Wang et al., 2004). The SSIM measurement consists of three terms which make it possible to detect the variation of luminance l(X,Y), contrast c(X,Y) and local structure s(X,Y) between the original image X and its version degraded Y.

$$SSIM(X, Y) = l(X, Y).c(X, Y).s(X, Y)$$

Global distortion is achieved by averaging these local measurements. The three local measures are defined by:

$$l(X, Y) = \frac{2.\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1}, \qquad c(X, Y) = \frac{2.\sigma_x\sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_2},$$
$$s(X, Y) = \frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3}$$

Where $\mu_x, \mu_y, \sigma_x, \sigma_y \text{ and } \sigma_{xy}$ are an average, a square root of variance and a covariance of x and y, respectively.

The constants C_1, C_2 and C_3 make it possible to guarantee the stability of the measurement in the homogeneous zones:

$$C_1 = \frac{C_2}{2}, \quad C_2 = (\alpha L)^2, C_3 \geq 0 \quad \text{and} \quad \alpha \ll 1$$

where L is the dynamic range of the pixel values. The two images x and y are broken down into blocks of the same size or analyzed through a moving window. The three quantities are then calculated in each of the windows and for each reconstructed image with Zonal DCT or FFZ_DCT.

To take into account the whole dimension of the scene, we have done a single overall quality measure of the entire image. We have used a mean SSIM to evaluate
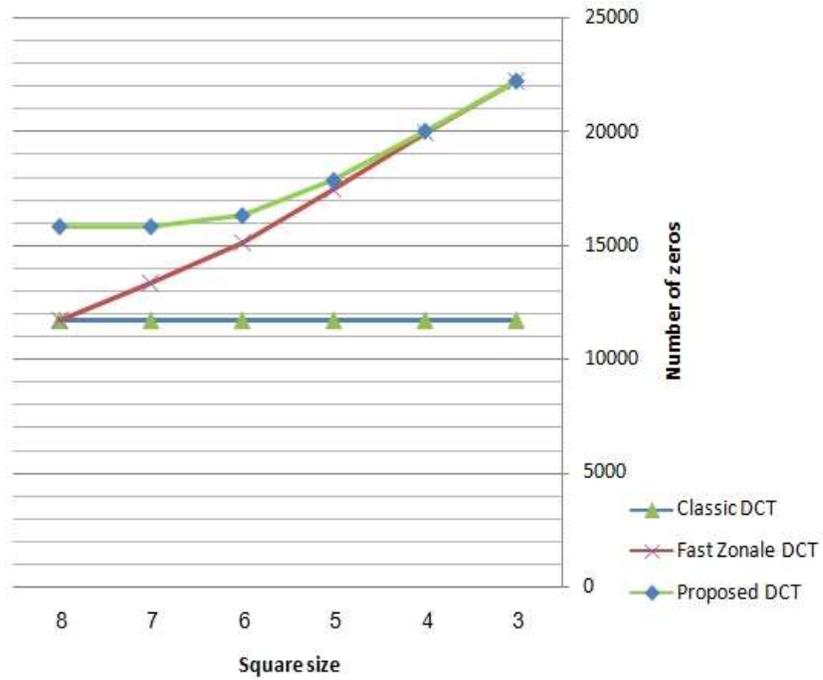
Figure 5. Comparison of zeros number for different square sizes.

Table 1. Comparison of image reconstructed for different square sizes.

Zonal DCT S=8	FFZ_DCT S=8
Zonal DCT S=6	FFZ_DCT S=6
Zonal DCT S=4	FFZ_DCT S=4
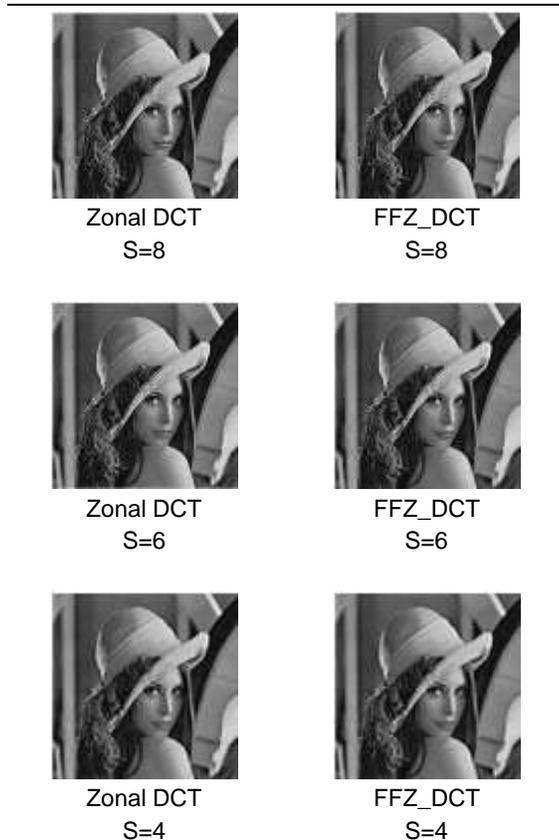
Table 2. Comparison of image reconstructed MSSIM for different square sizes

Parameter	S=4	S=6	S=8
MSSIM$_{Zonal\ DCT}$	0.794	0.790	0.789
MSSIM$_{FFZ\_DCT}$	0.804	0.799	0.790
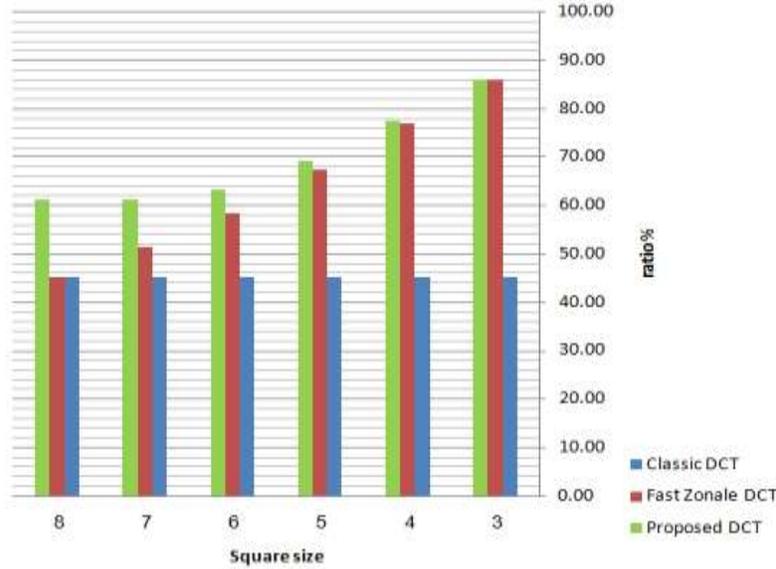
Figure 6. The filling rate of all blocks after the application of the three methods for different square sizes.

the overall image quality:

$$MSSIM(X,Y) = \frac{1}{P}\sum_{q=1}^{P} SSIM(X_q, Y_q)$$

where X and Y are the original and the reconstructed images. But, X_q and Y_q are matrix corresponding to the used window.

For X taken as the original image and Y taken as the reconstructed image with Zonal DCT then with FFZ_DCT, the obtained values of MSSIM are as indicated in the following.

Despite the reduction of the compression coefficients introduced by the FFZ_DCT, the estimation of the image degradation MSSIM relative to the FFZ_DCT is not different too much from that corresponding to the Zonal DCT. The importance of this new method is here again validated (Table 2).

In Figure 6, all methods provide a great percentage of zeros in image blocks in different square sizes. But, the FFZ_DCT produces more zeros at all and more quality.

For example, the FFZ_DCT of square size 6 preserves more necessary details of the chosen image and a rate

widely greater than 55% of initial values of this image filled by zeros, that is why it will be used in the next steps.

This increase in the number of zeros leads to a reduction in number of coefficients. Therefore, we realize in the same rate:

(1) a reduction of transmission time of any compressed image,
(2) the reduction of global energy consumption in the network, and
(3) the extension of the network lifetime.

The proposal's effect on different image sizes

In this step, the same image has been used but in different sizes. The quality of the reconstructed image is always the same with any method (Figure 7). The indicated methods seem to lead to the same result. But in fact, each of them is important. The most remarkable is the FFZ_DCT. Because, it is possible with this method to reduce the number of coefficients which will be treated in the corresponding algorithm. This has several consequences.

In Figure 8, it can be noticed that the image contains
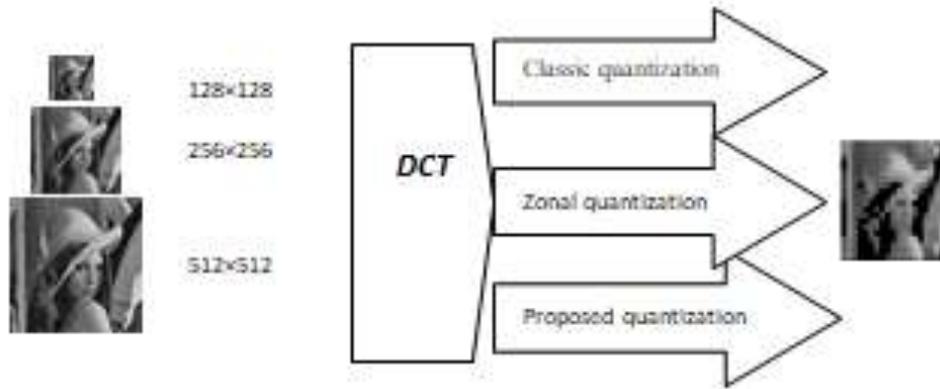
Figure 7. Image resolution for different image sizes.
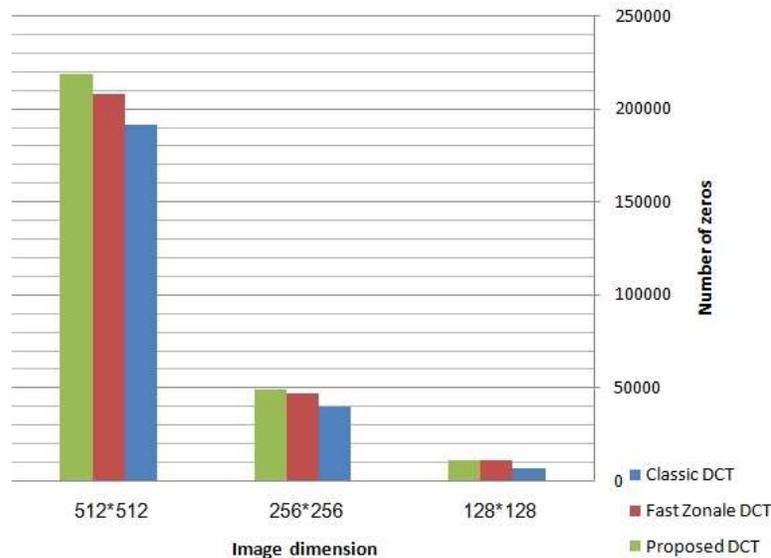
Figure 8. Comparison among the three approaches in terms of the number of zeros for different image dimensions.

enough pixels and the compression channel improves. This is logically applicable, because the number of zeros increases as the number of pixels and the blocks dimensions increase too. Therefore, we realize more:

(1) a reduction of transmission time of any compressed image,
(2) a reduction of energy consumption in the network and
(3) an extension of the network lifetime.

Entropy encoding phase

In source code analysis, we have used the entropy encoding phase (zigzag reading, RLE encoding, Huffman encoding) to evaluate the size of the binary output. The influence of the FFZ_DCT in terms of the bit stream sizes was noticed. The obtained results are shown in the following.

Evaluating the FFZ_DCT based on a single combination of filters

The graph in Figure 9 shows that the proposed approach FFZ_DCT produces always fewer bits to be transmitted. It corresponds to the green column. Moreover, that is so more whenever the image dimension is large enough. The other approaches are independent to filters. But, they depend on image dimension.
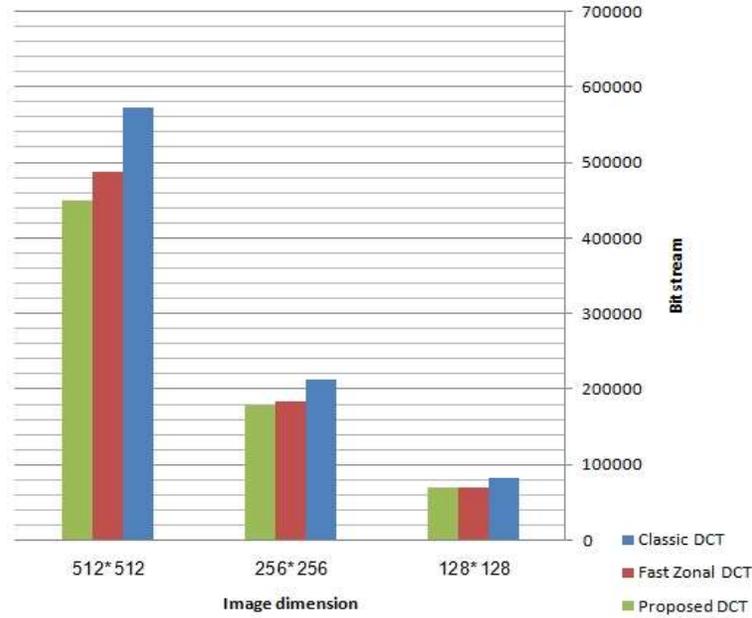
Figure 9. Comparison among the three approaches in terms of binary frame size of output, in different image dimensions.
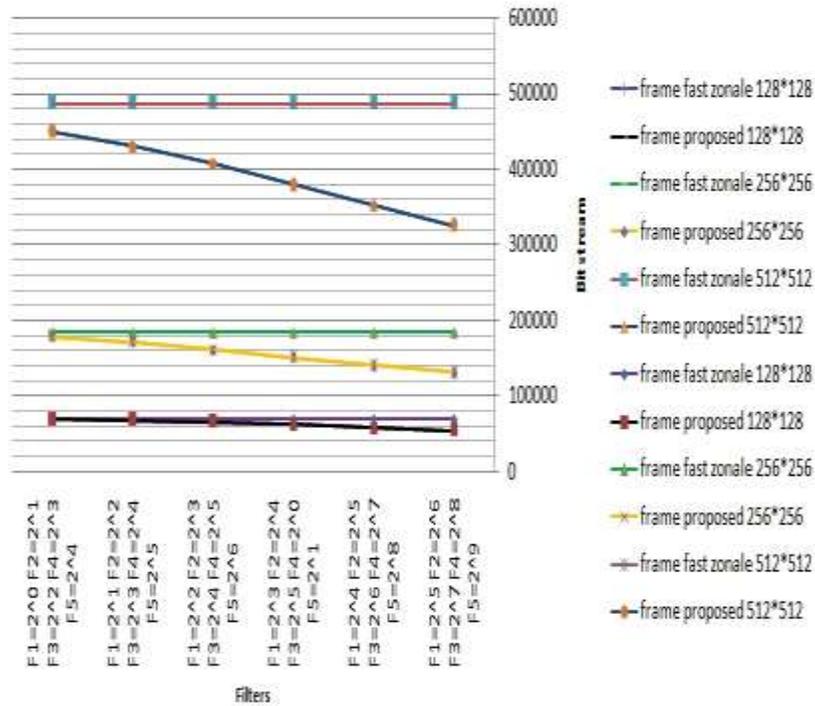
Figure 10. A comparison between FFZ_DCT and another approach in terms of output bit frame size, in different image dimensions and filters.

Evaluating the FFZ_DCT based on various combinations of filters

In Figure 10, for two frames and three images of different

sizes, the results show that there are fewer bits to be transmitted from one node to another specially with the application of the FFZ_DCT. In addition, the more the thresholds of applied filters increase the more the number
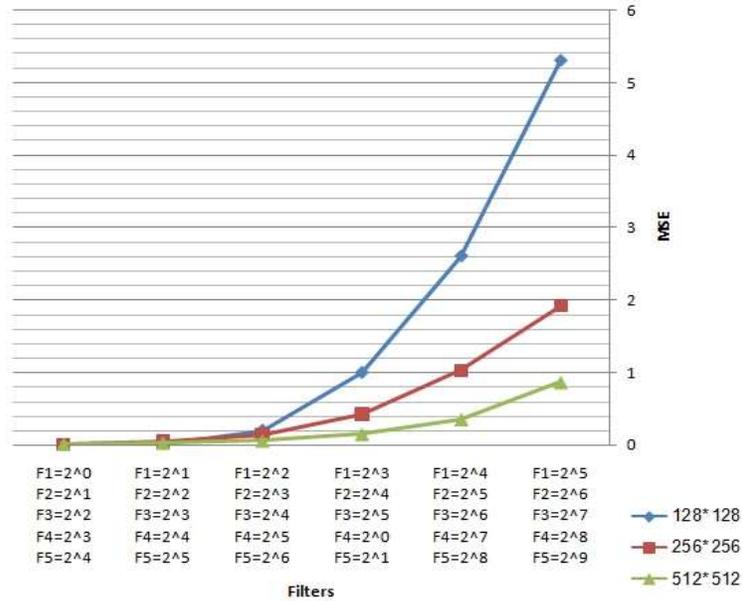
Figure 11. MSE approach proposed in different image dimensions and various filters combinations.

of bits to be transmitted decreased. Otherwise, the FZ_DCT is independent of the filters. But it leads to results depending on the image size and on the chosen frame. The corresponding curves are horizontal. Each one remains unchanged while changing the value of the indicated filters. With the FFZ_DCT, the following were realized:

(1) a reduction of transmission time of any compressed image,
(2) a reduction of global energy consumption in the network and
(3) an extension of the network lifetime.

The proposal's effect in terms of MSE

By applying MSE Formula 1 on the restored blocks matrix by only the proposed DCT, the results are as shown in Figure 11.
   In this Figure11, it is shown that the FFZ_DCT gives less error when the image is large enough. Indeed, the MSE remains between 0 and 1 for the largest image. In addition, the more the thresholds of applied filters increase the more the MSE increases too. Concerning images of small dimensions, the vision becomes unclear because the corresponding MSE is higher than 3. Therefore, we remark here again that the FFZ_DCT leads for any great dimension of compressed images to:

(1) a reduction of transmission time of any compressed image,

(2) a reduction of global energy consumption in the network and
(3) an extension of the network lifetime.

The proposal's gain

The graph in Figure 12, displays the gain of FFZ_DCT, which is estimated by calculating the following ratio = (proposed bit stream size / fast zonal bit stream size). The proposal's ratio increases when the image dimension increases too. This ratio depends also on the chosen filters. The more the thresholds of applied filters increase the more the indicated ratio increases too.
   For two sensors of standard 802.15-4 with the power 3 mW and with a flow rate of 250 kbps, the energy consumption and the reduction rate are very important. The more this rate increases the more the speed of transmission from one node to the other increases too. They are indicated in Table 3. They depend on the chosen filter threshold. The more the thresholds of applied filters increase the more the energy consumption decreases and more the reduction rate increases too. The result is presented for two methods. The reduction of this rate traduces here the speed of transmission.
   Therefore, we improve here again that the FFZ_DCT leads for compressed images, to:

(1) a reduction of transmission time of any compressed image from a node to another,
(2) a reduction of global energy consumption in the network and
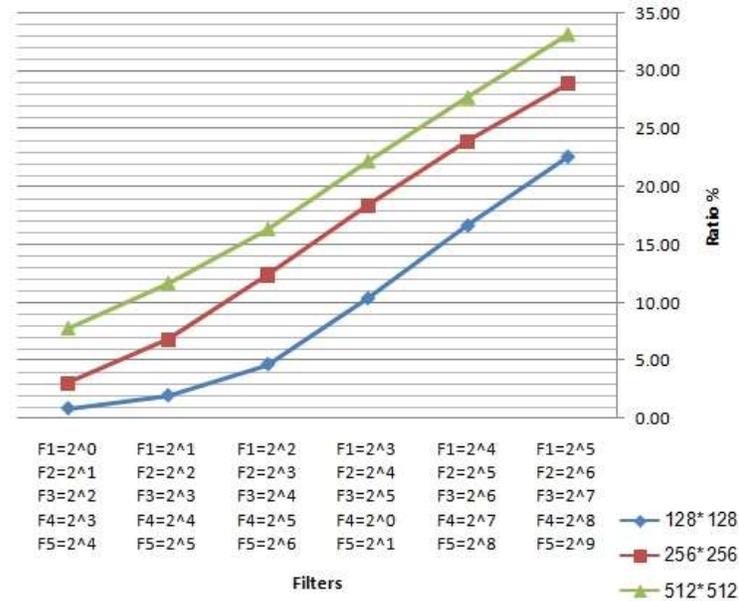
Figure 12. The ratio (proposed/zonal) in terms of binary frame size of output in different image dimensions and with various filters combinations.

Table 3. Estimation of the energy consumption by each approach.

Filter	Transmission energy of Zonal DCT (mJ)	Transmission energy of FFZ_DCT (mJ)	Reduction rate = (proposed / Zonal) (%)
F1=2^0 F2=2^1 F3=2^2 F4=2^3 F5=2^4	5.84	5,39	7.7
F1=2^1 F2=2^2 F3=2^3 F4=2^4 F5=2^5	5.84	5.16	11.64
F1=2^2 F2=2^3 F3=2^4 F4=2^5 F5=2^6	5.84	4.89	16.27
F1=2^3 F2=2^4 F3=2^5 F4=2^6 F5=2^7	5.84	4.55	22.09
F1=2^4 F2=2^5 F3=2^6 F4=2^7 F5=2^8	5.84	4.23	27.57
F1=2^5 F2=2^6 F3=2^7 F4=2^8 F5=2^9	5.84	3.91	33.05

(3) an extension of the network lifetime.

It was found out that there is an important added value in the use of this method FFZ_DCT.

Conclusion

In this paper, FFZ_DCT, a Filtered Fast Zonal Discrete Cosine Transform was proposed and evaluated. The FZ_DCT [2], some image filters and the mean square error were usd in this proposal. Redundant data were eliminated in each compressed image. Therefore, the relevant information were optimized in each image. The evaluation of this method is shown earlier in the experimental results. This is a new method of image processing dedicated to fast transmission in wireless cameras networks. It reduces considerably the power consumption of the sensors, extends remarkably the network lifetime and reduces transmission time of compressed images from node to node. In addition, this new approach allows an effective agreement between energy consumption and image distortion, as shown in the results. With this proposal, the importance of eliminating redundant data in the transmission of images permits to minimize the time of communication between nodes. The FFZ_DCT will become another mean of reducing more expenses in WSN. This new tool of image processing is very important and has a lot of applications, especially in WCN.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

ABBREVIATIONS

DCT, Discrete cosine transform; **WSN,** wireless sensors network; **WCN,** wireless cameras network; **MSE,** mean square error; **DC(.,.),** discrete coefficient; **FZ_DCT,** fast zonal discrete cosine transform; **FFZ_DCT,** filtered fast zonal discrete cosine transform; **RLE,** run length encoding; **LLM,** Loeffler-Ligtenberg-Moschytz; **LEACH,** low-energy adaptive clustering hierarchy; **SSIM,** structural similarity index measure; **MSSIM,** mean structural similarity index measure.

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