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HARDWARE IMPLEMENTATION OF DIGITAL IMAGE CODING USING FDCT

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ABSTRACT

Image coding becomes an interested issue for its extensive use in wide range of applications. This work deals with the Fast approaches of hardware implementation for Forward Discrete Cosine Transform (FDCT) and the Inverse Discrete Cosine Transform (IDCT). These approaches are normally used for image coding and decoding applications. The implemented approaches are built using hardware design with specific control parameters to speed up the processing. The implemented approach based on one dimensional Discrete Cosine Transform (1D-DCT) and fast transposing through high access memory that offer real time operation. The control system of flow of pixels is built to have two principal processing of rows and columns and the flow of coefficients comes from high speed access memory. The implementation of the system is done to achieve high speed and accurate results. The differences between the original image and the recovered image for all tested sizes are very small and it is about 10^{-16}.

Keywords: *FDCT, IDCT, Image Coding, Image Decoding.*

1. INTRODUCTION

Nowadays digital signal and image processing have important applications especially in industry [1,2], communications, robotics, computer vision, radio, Television and many other military and civil applications [3,4]. Image coding and decoding are denoted as an important fields of image processing [5,6,7,8]. Most of the published works at this filed are concentrated the accurate results and real time processing [9,10].

Digital representation of images offers many benefits but required big amount of data for representation [11,12]. On the other hand this open new issues to be considered such as storage devices and operating speed [13,14]. Therefore the reduction of data is an important solution to be implemented to make handling of high resolution digital images [15,16].

Several techniques and methods are explained to view the benefits of the fields of compression and coding [17,18]. Some techniques are simple that give low compression, other techniques are powerful and expensive [19,20]. Anyhow the relation between cost and quality is an important issue [21,22]. Considering a specific parameters for mixing between hardware and software are very important to design an image processing system [23,24].

Most of the implemented transform coding techniques using discrete cosine transform give significant compression with reasonable cost and quality [25,26]. Image coding leading to represent images using few number of bits as possible [27,28]. This operation have many applications in reduction of channel bandwidth required for image transmission and storage devices [29,30].

2. RESEARCH OBJECTIVE

The hardware implementation of digital image processing play an important role in many applications, including image coding applications. So this research discovered that large number of papers have been published on this subject. The aim of this work is to study the digital image coding technique applied on images using discrete cosine transform. Then this work try to address the design of an efficient approach of hardware implementation of digital image coding using fast discrete cosine transform and study the coefficients of both DCT and IDCT. So the main objective of this research is to offer an efficient image coding approach to achieve high accuracy and high speed.

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3. DISCRETE COSINE TRANSFORM

The Discrete Fourier Transform (DFT) [31] and Discrete Cosine Transform (DCT) [32] perform similar functions: they both decompose a finite-length discrete-time vector into a sum of scaled-and-shifted basis functions [33]. The difference between the two is the type of basis function used by each transform; the DFT uses a set of harmonically-related complex exponential functions, while the DCT uses only (real-valued) cosine functions [34].

Figure 1 shows both one dimensional Forward Discrete Cosine Transform (1D-FDCT) and one dimensional Inverse Discrete Cosine Transform (1D-IDCT) that are used for coding and decoding of signals.

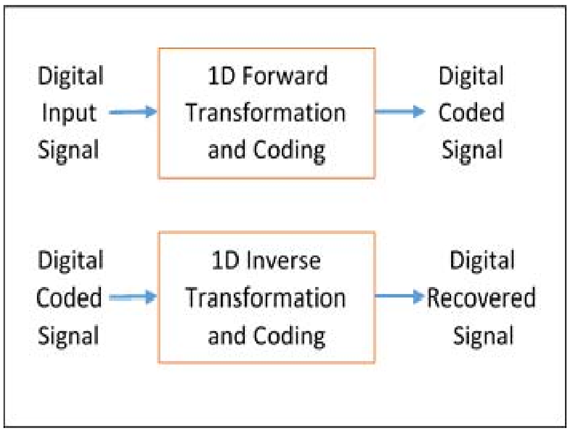

Figure 1 one dimensional discrete cosine transform

The forward 1D-DCT is given by the following equation [35,36]:

$$X(k) = c(k)\sum_{n=0}^{N-1} x(n)\cos\left[\frac{(2n+1)k\pi}{2N}\right] \qquad (1)$$

Where X(k) is the output coefficients values, x(n) is the input data values, N is the number of discrete values, n is the index of the input values, k is the index of the output values.

The inverse 1D-DCT is given by the following equation [37,38]:

$$x(n) = \sum_{k=0}^{N-1} c(k)\,X(k)\cos\left[\frac{(2n+1)k\pi}{2N}\right] \qquad (2)$$

Where

$$c(k) = \begin{bmatrix} \sqrt{1/N}\ for\ k = 0 \\ \sqrt{2/N}\ for\ k = 1,2,\ldots N-1 \end{bmatrix} \qquad (3)$$

Figure 2 shows both two dimensional Forward Discrete Cosine Transform (2D-FDCT) and two dimensional Inverse Discrete Cosine Transform (2D-IDCT) that are used for coding and decoding of two dimensional signals such as images.

The forward 2D-DCT is given by the following equation [39,40]:

$$X(k1,k2) = c(k1)c(k2)\sum_{n1=0}^{N-1}\sum_{n2=0}^{N-1} x(n1,n2)\cos\left[\frac{(2n1+1)k1\pi}{2N}\right]\cos\left[\frac{(2n2+1)k2\pi}{2N}\right] \qquad (4)$$

Where X(k1,k2) is the output square matrix coefficients values, x(n1,n2) is the input square matrix data values, N is the number of discrete values (rows and columns), (n1,n2) are the indices of the input values, (k1,k2) are the indices of the output values.

The inverse 2D-DCT is given by the following equation [41,42]:

$$x(n1,n2) = \sum_{k1=0}^{N-1}\sum_{k2=0}^{N-1} c(k1)\,c(k2)\,X(k1,k2)\cos\left[\frac{(2n1+1)k1\pi}{2N}\right]\cos\left[\frac{(2n2+1)k2\pi}{2N}\right] \qquad (5)$$

Where

$$c(k1) = \begin{bmatrix} \sqrt{1/N}\ for\ k1 = 0 \\ \sqrt{2/N}\ for\ k1 = 1,2,\ldots N-1 \end{bmatrix} \qquad (6)$$

$$c(k2) = \begin{bmatrix} \sqrt{1/N}\ for\ k2 = 0 \\ \sqrt{2/N}\ for\ k2 = 1,2,\ldots N-1 \end{bmatrix} \qquad (7)$$

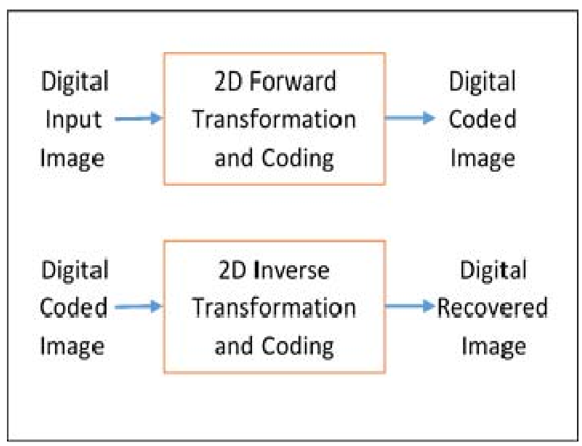

Figure 2 two dimensional discrete cosine transform

4. RELATED WORK

According to the huge amount of publications in this field, it is impossible to recover all the aspects of these publications. In this item some concentration on the most recent publications:

T. C. Tan et al. (2001), proposed a fast DCT algorithm that mapped to a hardware structure composed of log2N modules. This hardware structure can be used for serial bit or serial implementation of bit serial. Compared to other hardware deployment methods, the project provides a natural interface to sequentially submitted input data, enables high hardware utilization, requires low latency processing, and has a modular architecture that can be extended to support different processing sizes [43].

Tang Li (2004), optimized a technique based on the conservation of DCT energy assets, for motion estimation, DCT and quantification of standard video encoders developed. Firstly, proposed a stop criterion for motion estimation to reduce the number of control points to find the motion vectors and save the calculations. The advantage of introducing this stopping criterion lies in its adaptability to the quantization parameter and the applicability to various fast algorithms. Next, the DCT and the quantification are optimized together by plotting the remaining signal energy and eliminating unnecessary calculations in the DCT process and quantification. 2D-DCT based on DCT's fast Huang algorithm is presented to demonstrate the superiority of this algorithm to full DCT and a completely zero total block detection method. Although this approach is computationally efficient,, the algorithms do not indicate any obvious loss of quality [44].

Yi-Ming Zhou (2009), improved the coding of fractal images by provided efficient algorithms for encoding fractal images using a special unified feature and a DCT encoder. Depending on a necessary condition for the most appropriate search rule in fractal image coding, it treats the fast algorithm that uses a special unified function and can reduce the lookup space of course and exclude the sub-locks coincidences more inappropriate before the best matches. In order to improve the quality of the reconstructed image, a DCT encoder is combined to construct a hybrid fractal image algorithm. The experimental results show that the proposed algorithms can obtain reconstructed images of good quality and require much less time than the basic algorithm of fractal coding [45].

Hui Li et al. (2010), explained an inverse modified discrete cosine transform (IMDCT) approach and an efficient hardware accelerator architecture. The proposed fast algorithm is derived from the discrete cosine algorithm type IV transformed into discrete sine cosine Type IV. After the transformations, the computational elements continue to be recombined to share hardware resources. The experimental results show that the calculation cycles of the proposed algorithm are reduced by 20% and 51%, respectively, compared to two other fast algorithms reported. Using resource sharing and multiplexing techniques, the proposed hardware accelerator reduces 24% and 48% of transistors compared to two other methods respectively [46].

K. Viswanath et al. (2011), implemented an approach of image filtering in the transformation domain using a symmetric convolution in the DCT block space. Due to the application of the convolution multiplication property in the DCT domain, the filtering operation requires much less computation than its equivalent in the original signal and image space. To care for discontinuities along the boundaries of the blocks, the filtering is performed on a larger DCT block composed of adjacent blocks. Subsequently, the filtered DCT block is obtained by decomposing it. The proposed filtering technique achieves the same results of linear convolution in the space domain with a reduced cost. With the proposed filtering, it is possible to considerably accelerate the operation by ignoring certain elements in the filter matrices whose magnitudes are less than a threshold value. The standard deviation of the input blocks of the DCT domain is also taken into account for an additional reduction in the calculation cost [47].

Zhongwei He et al. (2012), proposed Markov-based approach to detect this specific artifact. First, the original Markov characteristics generated from transition probability matrices in the DCT domain is developed to capture not only the intra-block correlation but also inter-blocks between the DCT coefficients of the block. Then more functionalities are constructed in the DWT domain to characterize the three types of dependence between wavelet coefficients between positions, scales and orientations. Then, the support vector machine entity selection method is used to perform the task of reducing functionality, which facilitates the management of calculation costs. Finally, the support vector machine (SVM) is exploited to classify authentic and spliced images using the reduced final functionality vector. The results of the experiment demonstrate that the proposed approach can overcome some of the more advanced methods [48].

Lech Jóźwiak, Yahya Jan (2013), described a new multiprocessor based multiprocessor accelerator design methodology that addresses the architectural design challenges of multiprocessor processors for highly demanding embedded applications. Using the LDPC decoder design for the latest high-speed communication system standards as an application example that conducted extensive experimental research on multiprocessor design issues, as well as methodology and design framework. The experiments clearly demonstrated the existence of several complex architectural compromises that could only be solved by a spatial exploration of a combined quality design adapted to the micro and macro architects of the processors and the corresponding memory and communication architectures are provided by our method [49].

Hai Huang, Liyi Xiao (2014), designed a reconfigurable segmented processor for FFT / IFFT and DCT / IDCT calculations over a variable length variable length distance compatible with IEEE 754. This approach minimized storage and power consumption, a reconfigurable radix-4 butterfly to reduce the adders by 75% compared to the conventional butterfly radix-4 parallel and bank records structured partly-shared ping-pong provided cache mechanism ultimate data effective and specific means to achieve maximum utilization ratio of the resources adder and to ensure high performance for the pipeline design. The 4 input points adder merged point unit and the point to the floating product 2 input points are proposed, which can not only improve a signal to noise ratio by 3 dB, but also save 28% above in equipment compared to discrete implementations. The simulation results show that the latency for FFT calculations is approximately 25% of the design without loss of performance, and it reaches more than 139 dB SQNR [50].

Abdessalem Ben Abdelali et al. (2016), presented a hardware design for the discrete forward cosine transform (BinDCT) and its application in a programmable matrix grid array device. Different architectures of the module have been explored to ensure maximum efficiency. The development of these architectures included architectural design, timing and pipeline analysis, hardware description language modeling, design synthesis and implementation. The developed hardware module has a high efficiency in terms of operating frequency and material resources, which made it suitable for the latest video standards with high resolution image and refresh rate. A high hardware efficiency will make it a very good candidate for time-limited applications and resources. Compared to several recent implementations of discrete cosine transform approximations, it has been shown that the proposed module has the best performance [51].

D. Ravì et al. (2016), implemented an approach for generating specific segmented segments. We present two new features that use the quantified data of discrete cosine transformation in a Semantic Texton Forest (STF), combining color and texture information for semantic segmentation. The combination of multiple features in a segmentation system is not a simple process. The proposed system is designed to exploit complementary functionalities in a computationally efficient way. These functions describe complex textures represented in the frequency domain and not just simple textures obtained using differences in pixel intensity as in the conventional approach. Unlike existing methods, a limited amount of resources is required. The proposed method was tested in two popular databases: CamVid and MSRC-v2. The comparison with the recent advanced methods shows an improvement in the precision of the semantic segmentation [52].

C. J. Tablada et al. (2017), proposed two approaches of DCT with 8 points without multiplication based on the factorization of Chen and their fast algorithms are also derived. Both transformations are evaluated in terms of calculation cost, error energy and coding gain. Experiments are performed with a JPEG image compression system and the results are compared with competing methods. The proposed low complexity transforms are scaled according to the algorithm for 16 and 32 points approximations. The new transformation sets are integrated into the HEVC reference software to provide a fully compliant HEVC video encoding scheme. The approximate transformations can overcome traditional transformations and advanced methods at a very low cost of complexity [53].

Daniel Llamocca (2017), implemented a new methodology by recovering similar models known for graphics and isomorphic interconnections as hardware accelerators in the system design. It has been proposed an efficient approach that converges in polynomial time to find similar subgraphs. Then, an algorithm has been proposed to perform cluster programming and minimizing the overhead. All algorithms were written in Python to analyze the description of the data flow and check the accuracy of the proposed works. The proposed design flow was applied to five different programs that are sine,

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cosine, exponent, matrix multiplication and discrete cosine transform. These were described as a flow chart data and were used for comparison of the results. An estimation table has been developed that shows the hardware and software parameters of the data flow operators for the chronology and the analysis of the program area [54].

According to these related works, it is clear that these works are concentrated on study the design of algorithms to implement both DCT and IDCT. This approach try to implement a real time approach to perform the performance as well as the accuracy of the implemented algorithm. The proposed approach try to design and implement an efficient fast digital image coding using DCT and IDCT.

5. METHOGOLOGY

The methodology of this approach is concentrated on design and implementation of fast image coding. This methodology is explained in detailed in the following items.

5.1 Design Consideration

The design of the system is built to carry out fast processing issue through multiplications, additions and transposing operations via DCT function. The main idea of the operation is the partitioning of two dimensional matrix into set of rows that means 2D-DCT can be implemented via 1D-DCT of rows and columns respectively, and also it is true for 2D-IDCT.

Before implementing this approach, some notes must considered, these are as below:

- The first point is the dimension of the selected matrix it must be square matrix in order to avoid the complexity.
- The second point is the length of rows and columns of the selected matrix must be 2 to the power of integer that leads to fast processing.
- The third point is the selection of the weighting factors in both forward and inverse DCT in which the weighting factors are divided for both cases which are clear from equations 3, 6 and 7.

5.2 DCT System Implementation

The steps of the procedure of the DCT system implementation are explained as below (figure 3):

Coefficients calculation for both DCT and IDCT that generates the matrix multiplier with the input image matrix.
Transposing operation is implemented through the multiplication process by controlling the addresses of memory using programmable counter.
The timing controller generator is used to control the overall processing of the system via dividing the time according to the required process.

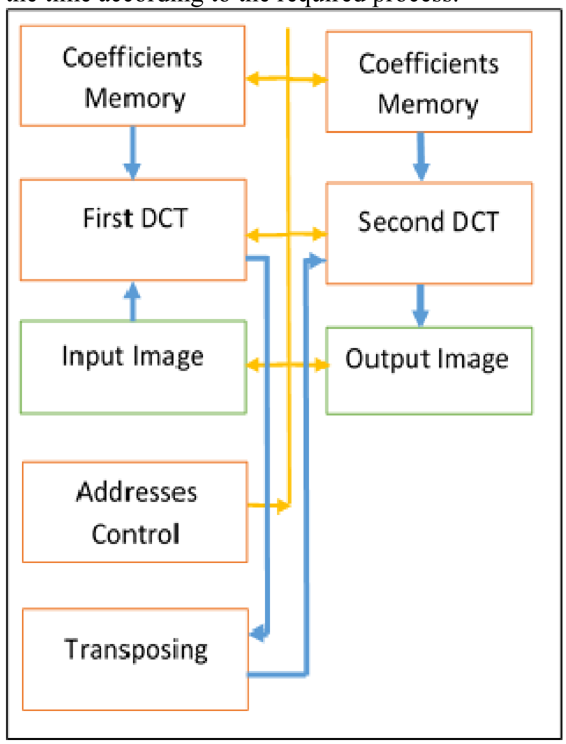

Figure 3 DCT system implementation

The multiplier is constructed of two chips of 16 bits SN54157A (considering the image data of eight bits per pixel). The multiplier output control is shown in figure 4 in which there are two main outputs; the first output is the low significant bits LSB (7:0) and the second output is the most significant bits MSB (15:8). LSB (7:0) is the normal output part and go directly to the output in case of the output values within 255. On the other hand when the output values exceed the value of 255, in this case there is an existing data at the part MSB (15:8).

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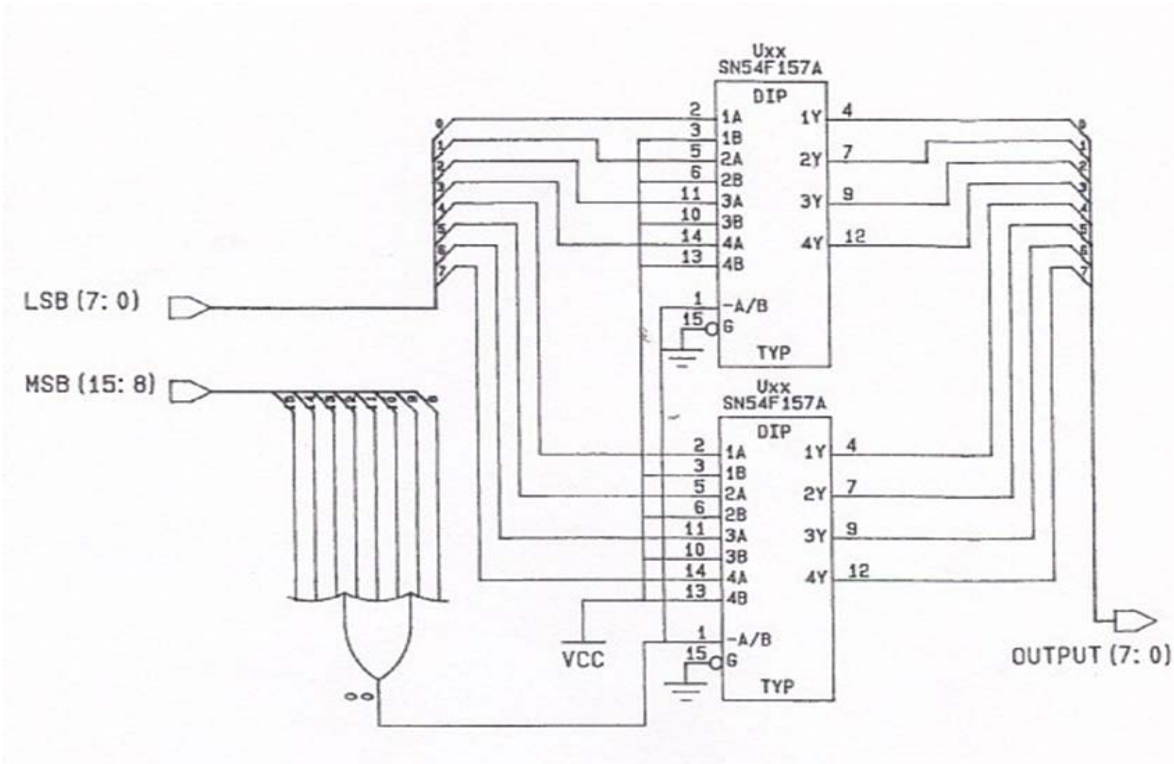

6. RESULTS AND DISCUSION

The DCT coefficients are shown in table 1 and demonstrated in figure 5. These coefficients can be used to implement the image coding approach according to direct reading of these coefficients. On the other hand the IDCT coefficients are shown in table 2 and demonstrated in figure 6. These inverse coefficients can be also used to implement the image decoding approach according to direct reading of these inverse coefficients.

According to these two tables it is clear that the IDCT coefficient are the transposed matrix of DCT coefficients in which can be simply applied via the implemented system within the sequence to serve the processing via the timing control. It is clear that there is a similarity between these two set of coefficients, so it can be used in bidirectional for image coding and image decoding.

Table 1 coefficients of DCT

	C1	C2	C3	C4	C5	C6	C7	C8
R1	256	256	256	256	256	256	256	256
R2	355	301	201	71	-71	-201	-301	-355
R3	335	139	-139	-335	-335	-139	139	335
R4	301	-71	-355	-201	201	355	71	301
R5	256	-256	-256	256	256	-256	-256	256
R6	201	-355	71	301	-301	-71	355	201
R7	139	-355	335	-139	-139	335	-335	139
R8	71	-201	301	-355	355	-301	201	-71

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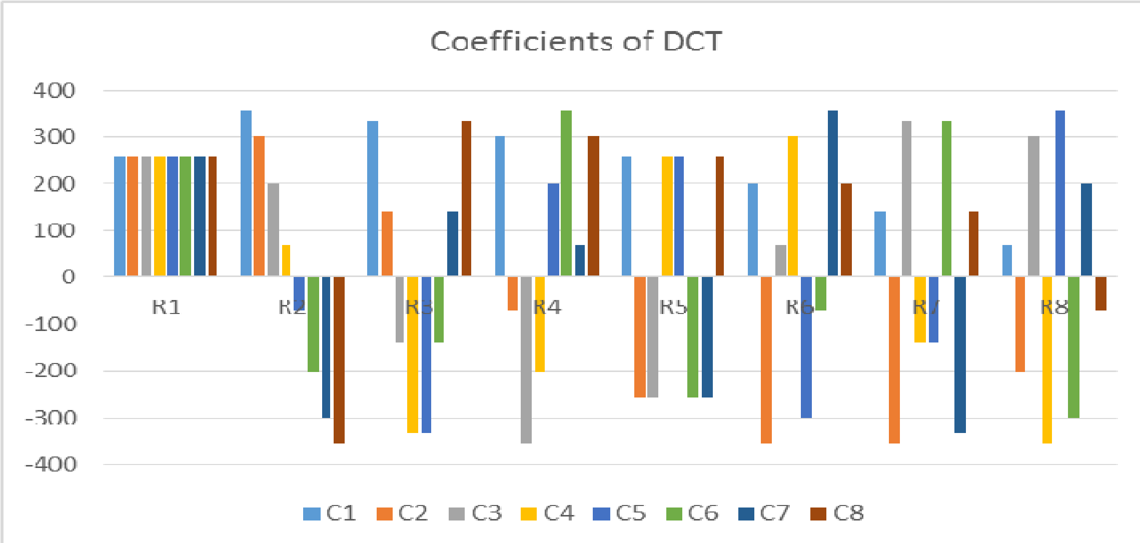

Figure 5 coefficients of DCT

Table 2 coefficients of IDCT

	C1	C2	C3	C4	C5	C6	C7	C8
R1	256	355	335	301	256	201	139	71
R2	256	301	139	-71	-256	-355	-355	-201
R3	256	201	-139	-355	-256	71	335	301
R4	256	71	-335	-201	256	301	-139	-355
R5	256	-71	-335	201	256	-301	-139	355
R6	256	-201	-139	355	-256	-71	355	-301
R7	256	-301	139	71	-256	355	-335	201
R8	256	-355	335	301	256	201	139	-71

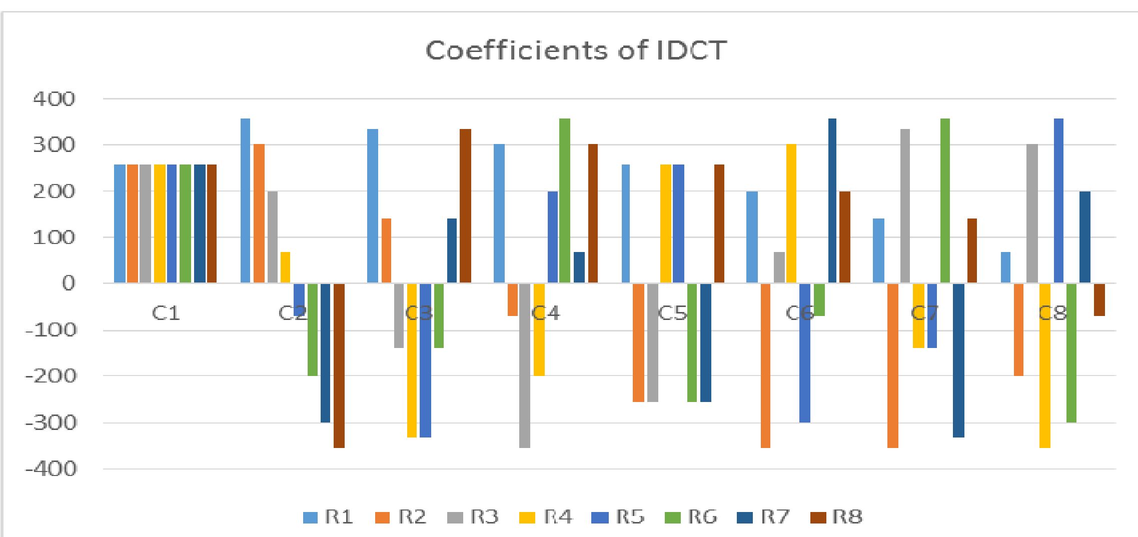

Figure 6 coefficients of IDCT

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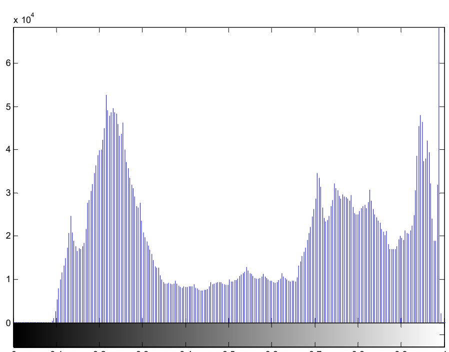
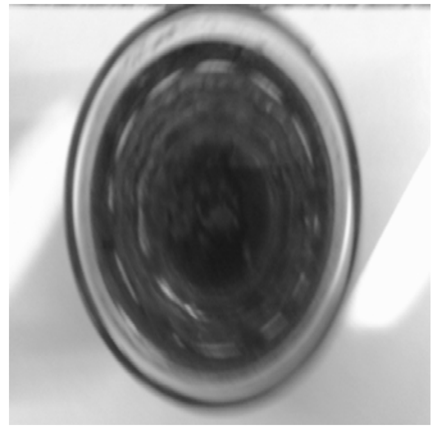
This approach is implemented on different images of water pollution that collected from real test of water pollution. All original images are of high resolution and of size 1920*2560. Then these images are resizing into three main types 256*256, 512*512 and 1024*1024. The first original image and its histogram are shown in figure 7, in which the original image is shown in figure 7a and then apply histogram operation to demonstrate the distribution of pixels as shown in figure 7b. The resizing stage is applied to all images to be ready for processing. Figures 8, 9 and 10 demonstrate the resized images of 256*256, 512*512 and 1024*1024 with their histogram respectively.

(a) Grayscale original image

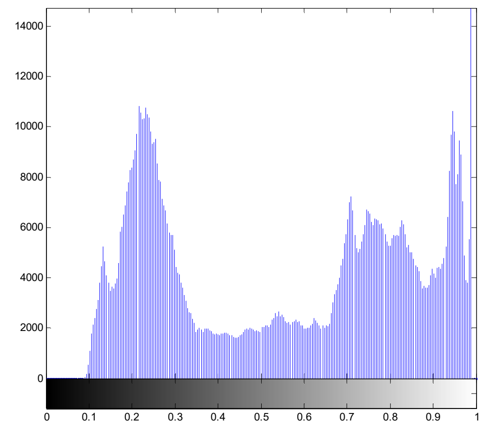


(b) Histogram of image in (a)

*Figure 7 first original image and its histogram (1920*2560)*

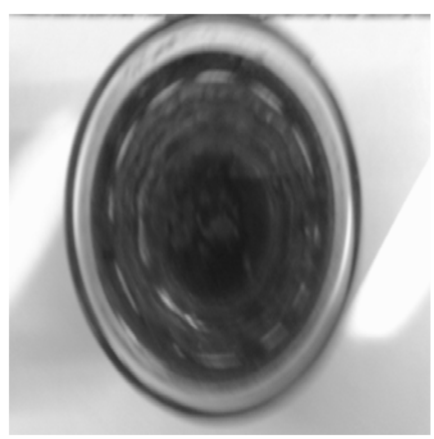


(a) Grayscale of original image



(b) Histogram of image (a)

*Figure 8 first original image and its histogram (1024*1024)*



(a) Grayscale of original image

Journal of Theoretical and Applied Information Technology
31st March 2018. Vol.96. No 6

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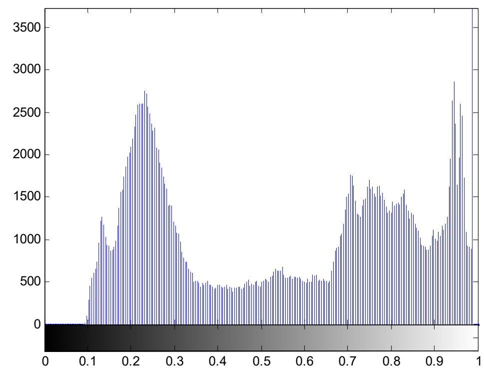
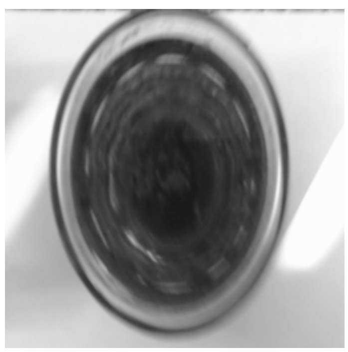
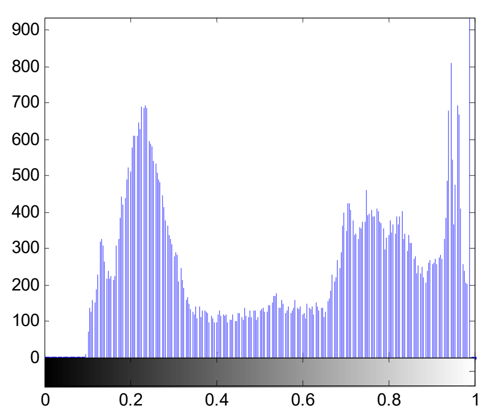


(b) Histogram of image (a)
*Figure 9 first original image and its histogram (512*512)*



(a) Grayscale of original image



(b) Histogram of image (a)
*Figure 10 first original image and its histogram (256*256)*

On the other hand DCT process is applied on the original images to encrypt these images, then IDCT is applied on the output of DCT to recover the image. Figure 11 shows the first original image after resized into 256*256, in which it is clear that this image has been encrypted into a new environment that is impossible to distinguish the details of the original image. After that applying IDCT approach to recover the original image as shown at the same figure. Comparing input and output images leading to high similarity and quality between original image and the recovered image, in addition that the compressed image occupied low space of size. The difference between the original image and the recovered image is very small and it is about 10^{-16}.

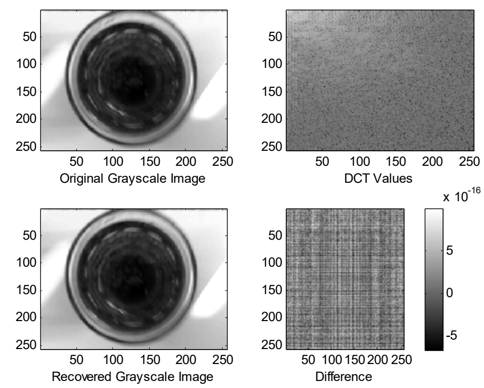


*Figure 11 first original image and its DCT (256*256)*

Figure 12 shows the first original image after resized into 512*512, in which it is clear that this image has been encrypted into a new environment. The difference between the original image and the recovered image is very small and it is about 10^{-16}.

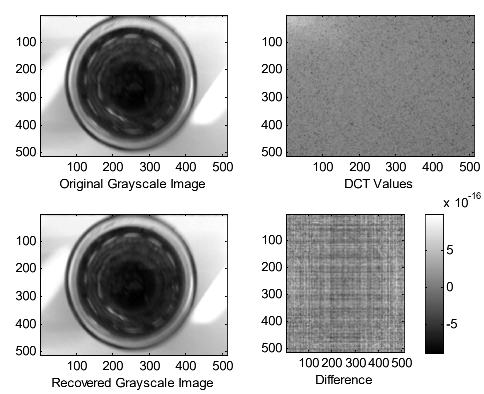


*Figure 12 first original image and its DCT (512*512)*

Journal of Theoretical and Applied Information Technology
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Figure 13 shows the first original image after resized into 1024*1024, in which it is clear that this image has been encrypted into a new environment. The difference between the original image and the recovered image is very small and it is about 10^{-16}.

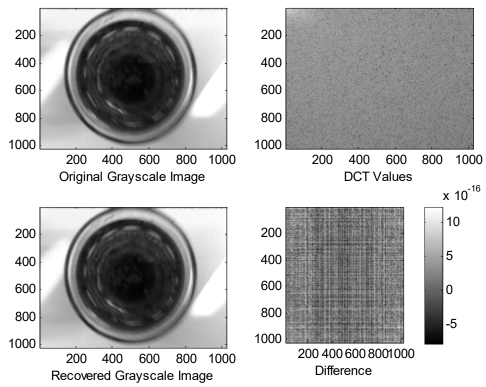

*Figure 13 first original image and its DCT (1024*1024)*

Figure 14, 15 and 16 show the second original image after resized into 256*256, 512*512 and 1024*1024 respectively, in which it is clear that this image has been encrypted into a new environment. Comparing input and output images leading to high similarity between original image and the recovered image, in addition that the compressed image occupied low space of size. The differences between the original image and the recovered image for all tested sizes are very small and it is about 10^{-16}.

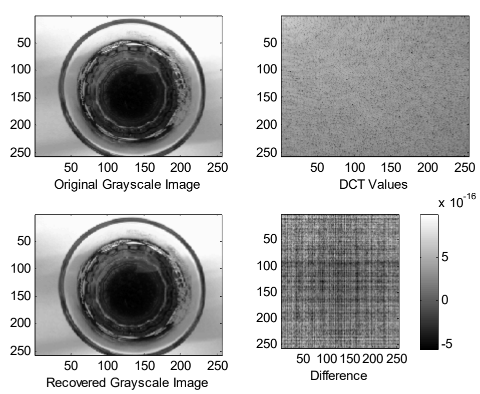

*Figure 14 second original image and its DCT (256*256)*

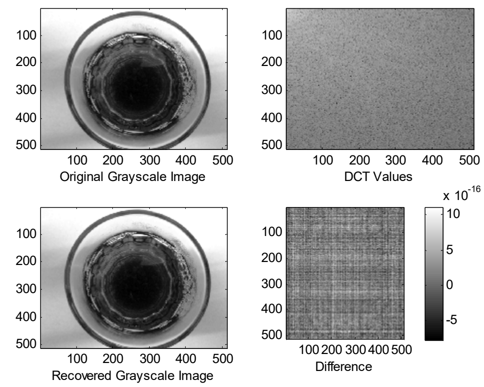

*Figure 15 second original image and its DCT (512*512)*

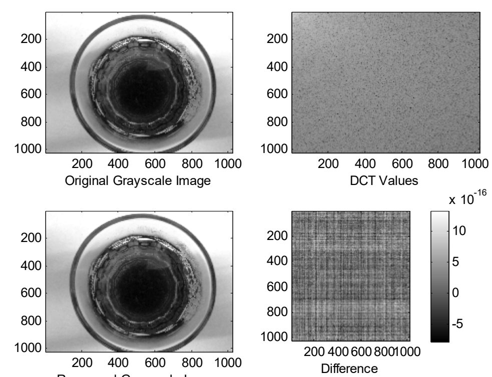

*Figure 16 second original image and its DCT (1024*1024)*

PSNR is the peak signal-to-noise ratio in decibels (dB). Figure 17 shows the PSNR values of the four tested images within the three sizes. This figure shows that the values of PSNR is around 40 dB and there is small increment with the increase of the image size.

The mean square error (MSE) is the squared norm of the difference between the input image and the recovered image divided by the number of elements. Figure 18 shows the MSE values of all tested images. These values are ranged from 13 to 5 according to the increment in the image size.

MAXERR is the maximum absolute squared deviation of the input image and recovered image. Figure 19 shows MAXERR values in which varied from 20 to 50 according to the contains of the image.

L2RAT is the ratio of the squared norm of the recovered image to the input image. Figure 20 shows L2RAT values in which varied from 0.9996 to 0.9999 depends on the image size.

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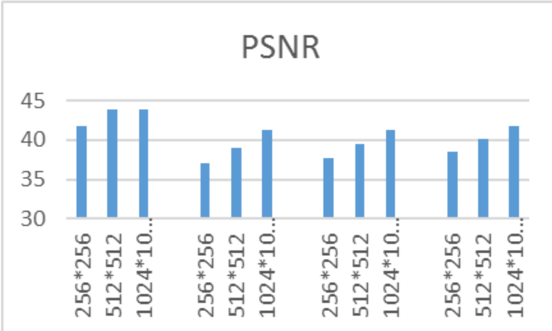

Figure 17 PSNR values

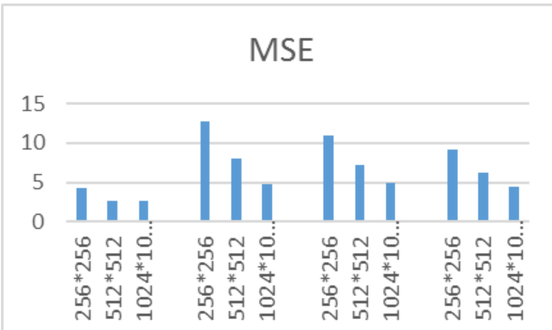

Figure 18 MSE values

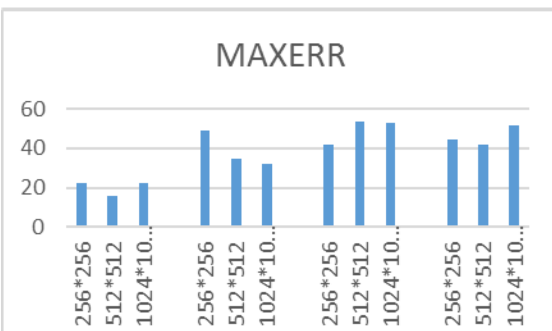

Figure 19 MAXERR values

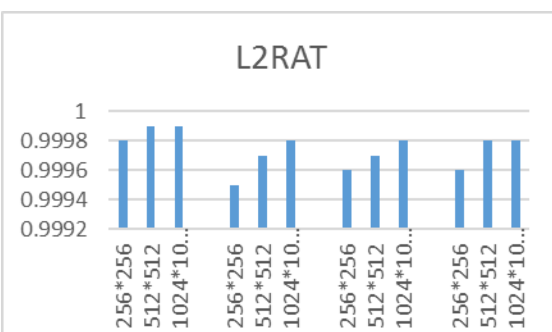

Figure 20 L2RAT values

7. CONCLUSIONS

Algorithms can be implemented via software or hardware forms. Software implementation is very important to achieve flexibility. Hardware implementation is very important to achieve real time processing and transmission. Two dimensional discrete cosine transform is an important technique for image coding operation. The implemented approach combined both forward and inverse discrete cosine transform. The implemented approach used high speed components to achieve the real time image coding processing. The overall system is simulated to obtain a good results for both forward and inverse discrete cosine transform applied for image coding. The recovered image guarantee high performance of the retrieved images. The differences between the original image and the recovered image for all tested sizes are very small and it is about 10^{-16}. At this accuracy, this approach can achieve high accuracy and high speed of processing that can be matched with the mentioned objectives.

REFRENCES:

[1] Phani Kumari Paritala, Shalini Manchikatla, Prasad K.D.V. Yarlagadda, "Digital Manufacturing- Applications Past, Current, and Future Trends", Procedia Engineering, Vol. 174, 2017, PP. 982-991.

[2] Luigi Pelliccia, Franziska Klimant, Agostino De Santis, Giuseppe Di Gironimo, Philipp Klimant, "Task-based Motion Control of Digital Humans for Industrial Applications", Procedia CIRP, Vol. 62, 2017, PP. 535-540.

[3] Margherita Pagani, Catherine Pardo, "The impact of digital technology on relationships in a business network", Industrial Marketing Management, In press, corrected proof, Available online 25 August 2017.

[4] Marina Cretich, George G. Daaboul, Laura Sola, M. Selim Ünlü, Marcella Chiari. "Digital detection of biomarkers assisted by nanoparticles: application to diagnostics", Trends in Biotechnology, Vol. 33, Issue 6, June 2015, PP. 343-351.

[5] R.D. Barrolleta, J. Pujol, M. Villanueva, "Comparing decoding methods for quaternary linear codes", Electronic Notes in Discrete Mathematics, Vol. 54, October 2016, PP. 283-288.

[6] Adam Woryna, "On the set of uniquely decodable codes with a given sequence of code

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

word lengths", Discrete Mathematics, Vol. 340, Issue 2, 6 February 2017, PP. 51-57.

[7] Tahar Brahimi, Farid Laouir, Larbi Boubchir, Arab Ali-Chérif, "An improved wavelet-based image coder for embedded greyscale and colour image compression", AEU - International Journal of Electronics and Communications, Vol. 73, March 2017, PP. 183-192.

[8] Song Wu, Ard Oerlemans, Erwin M. Bakker, Michael S. Lew, "Deep binary codes for large scale image retrieval", Neurocomputing, Vol. 257, 27 September 2017, PP. 5-15.

[9] Shinichiro Mori, "Deep architecture neural network-based real-time image processing for image-guided radiotherapy", Physica Medica, Vol. 40, August 2017, PP. 79-87.

[10] Laura Dzelzkaleja, Janis Kapenieks, "Real-time Color Codes for Assessing Learning Process", Procedia - Social and Behavioral Sciences, Vol. 231, 5 October 2016, PP. 263-269.

[11] Mona Abdolmaleky, Mosayeb Naseri, Josep Batle, Ahmed Farouk, Li-Hua Gong, "Red-Green-Blue multi-channel quantum representation of digital images", Optik - International Journal for Light and Electron Optics, Vol. 128, January 2017, PP. 121-132.

[12] Gabor T. Herman, T. Yung Kong, Lucas M. Oliveira, "Tree representation of digital picture embeddings", Journal of Visual Communication and Image Representation, Vol. 23, Issue 6, August 2012, PP. 883-891.

[13] Guangwei Xu, Yanke Bai, Qiao Pan, Qiubo Huang, Yanbin Yang, "Data verification tasks scheduling based on dynamic resource allocation in mobile big data storage", Computer Networks, Volume 126, 24 October 2017, Pages 246-255.

[14] Jiwei Li, Zhe Peng, Shang Gao, Bin Xiao, Henry Chan ,"Applications of provenance in performance prediction and data storage optimization", Computer Communications, Vol. 105, 1 June 2017, PP. 33-43.

[15] Nanfeng Liu, Paul Treitz, "Modelling high arctic percent vegetation cover using field digital images and high resolution satellite data", International Journal of Applied Earth Observation and Geoinformation, Vol. 52, October 2016, PP. 445-456.

[16] Yi Wan, Yongjun Zhang, "The P2L method of mismatch detection for push broom high-resolution satellite images", ISPRS Journal of Photogrammetry and Remote Sensing, Vol. 130, August 2017, PP. 317-328.

[17] Michael Parker, "Image and Video Compression Fundamentals", Digital Signal Processing 101 (Second Edition), 2017, PP. 329-346.

[18] Tanvir Rizvi, Max Wintermark, David Schiff, "Imaging of Epidural Spinal Cord Compression", Handbook of Neuro-Oncology Neuroimaging (Second Edition), 2016, PP. 723-744.

[19] Shilong Liu, Md Arifur Rahman, Ching-Feng Lin, Chin Yeow Wong, Haiyan Shi, "Image contrast enhancement based on intensity expansion-compression", Journal of Visual Communication and Image Representation, Vol. 48, October 2017, PP. 169-181.

[20] Ke-Kun Huang, Hui Liu, Chuan-Xian Ren, Yu-Feng Yu, Zhao-Rong Lai, "Remote sensing image compression based on binary tree and optimized truncation", Digital Signal Processing, Vol. 64, May 2017, PP. 96-106.

[21] C.E. Mercer, P. Hogg, S. Cassidy, E.R.E. Denton, "Does an increase in compression force really improve visual image quality in mammography? – An initial investigation", Radiography, Vol. 19, Issue 4, November 2013, PP. 363-365.

[22] Gurinder Singh, Kulbir Singh, "Improved JPEG anti-forensics with better image visual quality and forensic undetectability", Forensic Science International, Vol. 277, August 2017, PP. 133-147.

[23] Naman Govil, Rahul Shrestha, Shubhajit Roy Chowdhury, "PGMA: An algorithmic approach for multi-objective hardware software partitioning", Microprocessors and Microsystems, Vol. 54, October 2017, PP. 83-96.

[24] Marius Horger, Hendrick Ditt, Shu Liao, Katja Weisel, Christopher Kloth, "Automated "Bone Subtraction" Image Analysis Software Package for Improved and Faster CT Monitoring of Longitudinal Spine Involvement in Patients with Multiple Myeloma", Academic Radiology, Vol. 24, Issue 5, May 2017, PP. 623-632.

[25] Priya Selvam, Santhi Balachandran, Swaminathan Pitchai Iyer, Rajamohan Jayabal, "Hybrid transform based reversible watermarking technique for medical images in telemedicine applications", Optik - International Journal for Light and Electron Optics, Volume 145, September 2017, PP. 655-671.

[26] Jong Won Kim, Shin Ho Lee, Sang Uk Lee, "On the adaptive three-dimensional transform coding techniques for moving images", Signal

Processing: Image Communication, Vol. 6, Issue 6, February 1995, PP. 525-543.

[27] Seungcheol Choi, Oh-Jin Kwon, Jinhee Lee, Youngseop Kim, "A JPEG backward-compatible image coding scheme for high dynamic range images", Digital Signal Processing, Vol. 67, August 2017, PP. 1-16.

[28] Stephan Rein, Martin Reisslein, "Scalable line-based wavelet image coding in wireless sensor networks", Journal of Visual Communication and Image Representation, Vol. 40, Part B, October 2016, PP. 418-431.

[29] Golara Javadi, Atousa Hajshirmohammadi, Jie Liang, "Power and sub-channel optimization of JPEG 2000 image transmission over OFDM-based cognitive radio networks", Signal Processing: Image Communication, Vol. 58, October 2017, PP. 157-164.

[30] Hansong Xu, Kun Hua, Honggang Wang, "Adaptive FEC coding and cooperative relayed wireless image transmission", Digital Communications and Networks, Vol. 1, Issue 3, August 2015, PP. 213-221.

[31] Michael Parker, "Discrete and Fast Fourier Transforms (DFT, FFT)", Digital Signal Processing 101 (Second Edition), 2017, PP. 99-115.

[32] Vladimír Britaňák, "On the discrete cosine transform computation", Signal Processing, Volume 40, Issues 2–3, November 1994, PP. 183-194.

[33] Guang-Da Hu, Taketomo Mitsui, "Exponential stability of time-varying linear discrete systems", Linear Algebra and its Applications, Volume 528, 1 September 2017, PP. 384-393.

[34] Arianna Alfieri, Andrea Matta, "Mathematical programming time-based decomposition algorithm for discrete event simulation", European Journal of Operational Research, Vol. 231, Issue 3, 16 December 2013, PP. 557-566.

[35] K.R. RAO, P. YIP, "Application of the DCT", Discrete Cosine Transform, 1990, PP. 136-348.

[36] Yufang Bao, Hamid Krim, "Discrete Multi-Scale Transforms in Signal Processing", Academic Press Library in Signal Processing, Vol. 1, 2014, PP. 467-560.

[37] J.B. Lima, M. Barone, R.M. Campello de Souza, "Cosine transforms over fields of characteristic 2", Finite Fields and Their Applications, Vol. 37, January 2016, PP. 265-284.

[38] Mohamed F. Mansour, "Canonical transformations of the discrete cosine transform", Signal Processing, Vol. 87, Issue 6, June 2007, PP. 1355-1362.

[39] K.R. RAO, P. YIP, "Two Dimensional DCT Algorithms, "Discrete Cosine Transform, 1990, PP. 88-121.

[40] Soo-Chang Pei, Min-Hung Yeh, Two dimensional discrete fractional Fourier transform", Signal Processing, Vol. 67, Issue 1, 29 May 1998, PP. 99-108.

[41] Min Chen, Yuanzhi Zhang, Chao Lu, "Efficient architecture of variable size HEVC 2D-DCT for FPGA platforms", AEU - International Journal of Electronics and Communications, Volume 73, March 2017, PP. 1-8.

[42] Chun-Su Park, "Two-dimensional discrete cosine transform on sliding windows", Digital Signal Processing, Volume 58, November 2016, PP. 20-25.

[43] T. C. Tan, GuoanBi, Yonghong Zeng, H. N. Tan, "DCT hardware structure for sequentially presented data", Signal Processing, Vol. 81, Issue 11, November 2001, PP. 2333-2342

[44] Tang Li, "Computation reduction for standard-based video encoders based on the energy preservation property of DCT", Signal Processing: Image Communication, Vol. 19, Issue 5, May 2004, PP. 457-464.

[45] Yi-Ming Zhou, Chao Zhang, Zeng-Ke Zhang, "An efficient fractal image coding algorithm using unified feature and DCT", Chaos, Solutions & Fractals, Vol. 39, Issue 4, 28 February 2009, PP. 1823-1830.

[46] Hui Li, Ping Li, Yiwen Wang, "An efficient hardware accelerator architecture for implementing fast IMDCT computation", Signal Processing, Vol. 90, Issue 8, August 2010, PP. 2540-2545.

[47] K. Viswanath, Jayanta Mukherjee, P.K. Biswas, "Image filtering in the block DCT domain using symmetric convolution", Journal of Visual Communication and Image Representation, Vol. 22, Issue 2, February 2011, PP. 141-152.

[48] Zhongwei He, Wei Lu, Wei Sun, Jiwu Huang, "Digital image splicing detection based on Markov features in DCT and DWT domain", Pattern Recognition, Vol. 45, Issue 12, December 2012, PP. 4292-4299.

[49] Lech Jóźwiak, Yahya Jan, "Design of massively parallel hardware multi-processors for highly-demanding embedded applications", Microprocessors and Microsystems, Vol. 37, Issue 8, Part D, November 2013, PP. 1155-1172.

ISSN: 1992-8645 www.jatit.org E-ISSN: 1817-3195

[50] Hai Huang, Liyi Xiao, "CORDIC based fast algorithm for power-of-two point DCT and its efficient VLSI implementation", Microelectronics Journal, Vol. 45, Issue 11, November 2014, PP. 1480-1488.

[51] Abdessalem Ben Abdelali, Ichraf Chatti, Marwa Hannachi, Abdellatif Mtibaa, "Efficient BinDCT hardware architecture exploration and implementation on FPGA", Journal of Advanced Research, Vol. 7, Issue 6, November 2016, PP. 909-922.

[52] D. Ravì, M. Bober, G. M. Farinella, M. Guarnera, S. Battiato, "Semantic segmentation of images exploiting DCT based features and random forest", Pattern Recognition, Vol. 52, April 2016, PP. 260-273.

[53] C. J. Tablada, T. L. T. da Silveira, R. J. Cintra, F. M. Bayer, "DCT approximations based on Chen's factorization", Signal Processing: Image Communication, Vol. 58, October 2017, PP. 14-23.

[54] Daniel Llamocca, "Self-reconfigurable architectures for HEVC Forward and Inverse Transform", Journal of Parallel and Distributed Computing, Vol. 109, November 2017, PP. 178-192.