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Design Polynomial IIR Digital Filters of the Integer Parameters Space Use to Compress Image Data

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ABSTRACT: Polynomial IIR digital filters play a crucial role in the process of image data compression. The main purpose of designing polynomial IIR digital filters of the integer parameters space and introduce efficient filters to compress image data using a singular value decomposition algorithm. The proposed work is designed to break down the complex topic into bite-sized pieces of image data compression through the lens of compression image data using Infinite Impulse Response Filters. The frequency response of the filters is measured using a real signal with an automated panoramic measuring system developed in the virtual instrument environment. The analysis of the output signal showed that there are no limit cycles with a maximum radius of poles of 0.96 in the polynomial bandpass filters. Thus, all the functional requirements for the Integer Parameters Space of the proposed polynomial IIR digital filters were met. The results showed that the data compression and size reducing of an image file is processed without significantly impacting of visual quality. This is achieved by removing redundant or unnecessary information from the image while preserving the important details which removes unnecessary data to make the file smaller and more manageable.

Keywords: Polynomial Filters, SVD Algorithms, Image Compression, Image Processing

1. INTRODUCTION

In recent, Polynomial Infinite Impulse Response (IIR) digital filters play vital role of filters types that used in digital signal processing to process data such as image processing. These filters are characterized by having an infinite impulse response, which means that they can continue to affect the output data even after the input data signal is stopped [1]. In the context of image data compression, polynomial IIR digital filters help in removing noise and unwanted information from the image while preserving the important features. This achieves by applying mathematical operations on the image data to enhance the quality and reduce its size. On the other hands, Singular Value Decomposition SVD algorithm are a powerful mathematical tool used in various fields, including image processing [2]. This algorithm decomposes a matrix of integer parameters into three simpler matrices, making it easier to analyze and manipulate the data. In the context of image compression, SVD algorithm help in identifying and preserving the most important information in an image while discarding the redundant details [3]. By combining polynomial IIR digital filters with SVD algorithm, we can effectively compress image data without compromising on its quality [4]. The IIR filters help in pre-processing the image data, while the algorithms optimize the compression process by retaining the essential features of the image. Thus, the grouping of SVD and IIR digital Filters would be efficient for image compression.

However, the quality of the image compression is another significant matter of this research. It is tried to make the application of IIR recognizes the correlation of integer parameters space in the color images [5]. Also, it is already proven that the SVD is the best among all other eigen-based techniques. Moreover, the compression with IIR should be considered three filters to build up the difference equations for red, green, and blue components in the color images. In addition, there is a requirement to prove that the basic RGB and composite color model works probably with IIR digital

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filters [6]. Furthermore, the storage of color images considers large and dynamic field and recognizing the impact of color images in such environments, it is clear that image compression will continue to be a fruitful research and development area. Hence, the outcomes of applying image data compression technologies should definitely return a benefit from reducing storage, cost and improving the response times of complex color image processing applications.

2.THEORETICAL BACKGROUND

2.1 SINGULAR VALUE DECOMPOSITION (SVD)

SVD is essentially factorizing the specified matrix into several matrices [7]. It factorizes the assumed matrix with m number of rows and n number of columns to produce orthogonal matrices. These matrices comprise of nonnegative integers that called as singular values of the m x n columns of which are known as left and right singular vectors respectively [8, 9].

The given matrix could be calculated as the following steps:

- The given matrix M can be calculated as $M=U\Sigma V^t$ that we want to decompose.
- The left singular vectors U which is comprise eigenvectors of the M.
- The Σ-is considered as the diagonal matrix that comprising eigenvectors of V values.
- The right singular vectors V which is comprise eigenvectors of the M.

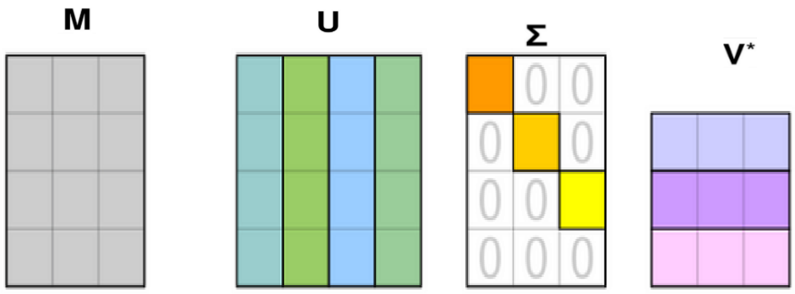

FIGURE 1. displays the matrices gained by splitting the M matrix

The above figure1 showed how the matrix M are splits into simpler matrices as explained in the above. Matrix M is decomposed into three different matrices which are of U, Σ and V [10]. However, implementation of such decomposition does not donate for compression and maximum singular values would be discarded whereas a few of them would be retained. Therefore, the employment of polynomial IIR digital filters would offer flexibility and efficiency in processing integer values, mainly in the situation of image data compression[11].

2.2 INTEGER PARAMETERS SPACE

Integer Parameters Space play vital role for image processing applications which is confining with the various filters that simplify the maintenance implementation and improves the computational efficiency [12]. The combination of polynomial IIR filters within the integers state space that can be provided through the Integer Nonlinear Programming (INP) method. In this circumstance, integer state space is considered principally as the multidimensional space of integer parameters input filters coefficients and main integers of operations on data processing in the digital filtering algorithms [13]. Basically, integer operations on any digital application are performed more faster than real control operations. The number of rounds of the vital processor unit required for the implementation of basic integer operations is significantly less. For instance, for the C8051F120 microcontroller processor, which can function with both integer and real data formats, main addition operations computed seven times faster, and multiplication processes are more than four times faster for integer mathematics in evaluation with real designs. The INP technique permits to design efficiently integer digital filters (IDF) with a given size of data word and maximum contentment of the requirements for the set of frequency features of the filter with a random form of their requirement. The transfer function of a polynomial integers filter is known to be computed by the following expression [14].

$$K(p)={K_0}/{v(p)} \qquad (1)$$

where v (p) is the integers polynomial of direction n, the roots that are placed in the left half-plane of the compound frequency p=□+j□, and the constant factor K0 regulates the filter program coefficient at zero frequency [15]. For discrete digital systems, the integer polynomial is written qualified to the complex variable and has roots only exclusive the unit circle in the z – plane. Thus, a polynomial filter does not have transmission coefficient irregular zeros, and their poles are finite. This delivers a higher stage linearity and stability of the polynomial structure and the implementation compared to linear circuits with finite zeros of the transfer coefficient would be less complex. In addition, the processing time for computing the response of a polynomial filters during their physical implementation into a digital platform is meaningfully less.

The comparisons among the selectivity of several categories of integer digital filter would be shown in the example of Fig.1 s by synthesizing a low-pass filter of the twelfth directive (N = 12) with a passband of 0-0.25 and the relation frequency scale f/fs. The conversion band 0.25 - 0.3 and an out-of-band destruction level of 60 db. The model of the IIR filters of full structure with finite zeros and transfer function has the best selectivity [15].

The single section difference equation represented in the following equation:

$$y_n = \left(b_0 x_n + b_1 x_{n-1} + b_2 x_{n-2} - a_1 y_{n-1} - a_2 y_{n-2}\right) / a_0 \qquad (2)$$

The above equation of the specification for an IIR filters would be represented as a twelfth order as shown in Figure2[15].

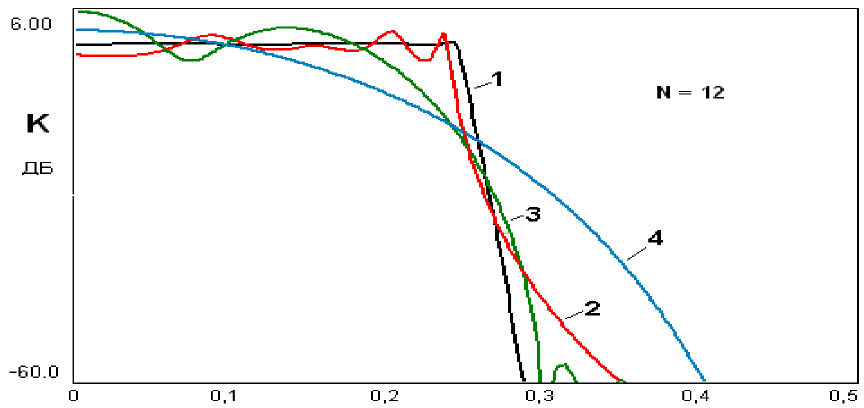

FIGURE 2. Comparison of the selectivity of digital filters

The choosiness curve 4 has a FIR filter with a difference equation as the following function (3)

$$y_n = \left(b_0 x_n + b_1 x_{n-1} + b_2 x_{n-2}\right) / a_0 \qquad (3)$$

and the regularity condition of the impulse response (IR) satisfied. The linearity of the frequency response is visible equally in the passband and in the stopband of the FIR filters. In FIR filters with permitted coefficient, the choosiness is meaningfully higher (curve 3) and when they are synthesized taking into account phase requirements, the essential level of linearity of the segment reply in the passband of the IIR filters can be provided[16]. Polynomial IIR filters (curve 2) noticeably surpass FIR filters in their selectivity, inhabiting a middle position between IIR filters of the full structure with finite zeros and FIR filters with asymmetric response. Meanwhile, the sum of operations required to calculate the response of a polynomial IIR and FIR filter is identical and nominal. Consequently, for many practical applications, polynomial digital filters are a practical possibility.

2.3 MODELING AND SYNTHESIS OF POLYNOMIAL FILTERS

References Currently, the proposal of recursive filters in the form of connection of units of the initial or second instruction of direct form is used most often in practice. The structure of the irreducible polynomial would be carried out by employing the comprehensive search method and experiments [17]. The allocation function for a recursive IDF, consisting of a typically connection of m seconds where instructions of polynomial sections are (m=N/2, where N is the total filter directive), as shown in the following formula:

$$H(z) = \prod_{i=1}^{m} \frac{b_{0i}}{a_{0i} + a_{1i} z^{-1} + a_{2i} z^{-2}} \qquad (4)$$

The complex variable z is turning to the depiction of the frequency response as the formula:

$K(e^{j\omega}) = \left|K(e^{j\omega})\right| \cdot e^{j\varphi(\omega)}$ takes the value $z = e^{j\omega}$, and $\omega = 2\pi f / fs$ is the normalized status.

The coefficients of the response formula (1) are integer, and their variation range is determined by the allocated word length of filter coefficients. From (1) it is easy to acquire the difference equation for a single segment of the filters:

$$y_n = \left(b_0 x_n - a_1 y_{n-1} - a_2 y_{n-2}\right)/a_0 \qquad (5)$$

Where X n, Yn are input and output integers of the time sequences.
As shown above from (5), when computing the filter response equation, the division by the integers normalizing factor a0 would be completed, that could be implemented by the bit-shift process provided that each i-th coefficient goes to the integer binomial series (series of 2n):

$$a_{0i} \in \left\{ 2^q \right\}, \quad q = \overline{0, W_k - 1} \quad i = \overline{1, m} \qquad (6)$$

Where the W is the bit word length of integer coefficients of binomial series formula.

The structure of a polynomial integer filters is shown in figure 2 below and the segment corresponding to the difference equation. The structure shows how to compute the filter response formula, besides conventional addition, multiplication operations, main operating is based on shift by B=log2a0 bits, utilized to implement integer division via the binomial factor.

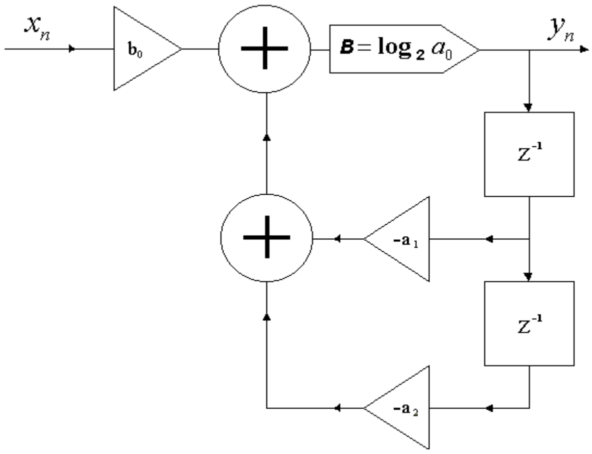

FIGURE 3. The construction of a polynomial IDF

In addition, the recursive filter will be stable if all the poles pi of the transfer formula is inside the unit circle in the z-plane:

$$\left|Zp_i\right| < 1 \qquad (7)$$

Moreover, the standard condition is necessary, but still far from sufficient, since the stability of an IIR filter, as a feedback system, can be reduced by limit cycles, though it appears to be stable as per relative (4) the filter begins to display unbalanced behavior, resulting in periodic fluctuations at the output. Thus, small limit rounds arise due the absence of an input and output indicators where the computational errors would not reach zero and often under oscillatory circumstances. The limit rounds arise when the amplitude of the output indicator is increased and resulting in an overflow[15]. This considered as the possibility of the occurrence of limit rounds that increases with the growing of the recursive filters and is basically determined by the quality factor of the poles of its transfer formula (1). In addition, it would be difficult to carry out a theoretical computation of limit cycles even for IIR filters of low direction. Consequently, an effective way to remove limit cycles and reduce the permissible Q factor of the poles of its transfer function. And since the Q factor of the poles is proportional to their radius in the z-plane, it will be enough to set a smaller value of the suitable radius of the magnates of the transfer formula to resynthesize the filter. Thus, the collective stability form of the projected polynomial filters occupied into account the lack of limit rounds as shown in the following formula [15]:

$$| Zp_i | < r_{\max} \qquad (8)$$

where max is the permissible determined radius of the magnates of the transfer formula of the filter in z-plane, at which no limit rounds in the system occur.

Moreover, it would possible to require any chosen value of the maximum radius of the magnates and zeros in the INP bundle when solving a specific project issue. Through the practical experience the synthesis with a minor value of the maximum radius, constantly possible to obtain a project solution without any limit cycles, although the filter selectivity would be decreases at the same time.

The outcomes of the intermediate computations necessary for conniving the polynomial IDF response for all integers. Also, the outcome of multiplying integers would be entirely filled determinate no quantization requirements for implementation the digital applications that assumed word length Wk at data depiction of the coefficients. The assumed bits of quantization of the input signal Wx, would be sufficient to select an internal storage with a formula of $W_{ak} = W_x + W_k$ bits to store the outcome of integers multiplication. The overflow oscillations, which is the occurrence of large limit rounds through the complete data size overflow of the storing register. The computation of bits considering that the accumulation of the sum of integers multiplication as algebraic addition. This is considered as the sign of the terms that significantly decreases the bites of the outcome. Hence, the integer polynomial filters considered the source of noise for each segment of the origin that based on shift operations.

2.4 IIR BANDPASS FILTERS

The bandpass filters considered as magnate forms for constructing digital filters of the scaling process that is required to improve the filters distribution over different phases. This function allows the filters to work in varied dynamic range of the input indications. However, for magnate IIR bandpass filters would be easier to compute various integers not by directly requiring a slight spread of the transfer ratio of individual parameters through the polynomial filters combination[18]. The current studies shown a significant dynamic range of transfer coefficients reduction. In addition, the coarse cascade scaling considered the main approach for the producing dynamic polynomial filters with noticeable reduction. The necessities of indicator function in magnates are formulated by efficient constraints for the combination extremum issue of the INP synthesis.

Moreover, the numerical solution of the extremum problem INP considered an effective combination technique (5), for designing a polynomial filter, and play vital role for utilizing the in a discrete grid of the Gray code[15]. This technique is improved for finding solutions in the discrete integers symbol manner of a multidimensional search area. The vector IXO that reduces the scalar objective formula F(IX) on the group of acceptable integers outcomes (6), is considered as an effective key to the problem of producing a polynomial IDF from a group of contrary characteristics.

Thus, this would be distinguished as an efficient search design approach, an intellectual process and in contrast to the classical analytical scheming. Various scenarios for explaining a complex scheme problem that included numerous specific methods and services can be implemented by a trained search designer to effectively answer a complex problem. A characteristic scenario for the search project of high-order magnate IDFs is considered as a dynamic system of search tasks with a phased growth in the demand of designing filters. In addition, the low-order design is implemented to fulfillment the collective necessities by polynomial filters that would be low cost. Furthermore, the increasing in the reliability of the global extreme recognition in the search of INP at the initial phase, would be desirable to implement a such search model[15, 18]. In addition, the additional phase could be applied as a source and the order of the filters would be increased by adding one more segment of the additional order. This is usually applied by duplicating the previously initiate coefficients of one of the segments that can be finished automatically within the combination bundle. At the end, numerous iterations at the final order of the designed polynomial filters would be determined the error of complex cumulative requirements within a specified acceptance.

3.THE PROPOSED WORK

In this section, the framework of the proposed image compression method using IIR Filters would be introduced. The IIR Filters are mainly based on reducing the singular values in the diagonal matrix that would be help in the image compression. As the consequence of this approach, initial value of the diagonal matrix comprises most important information and the additional values in the matrix would contain the less important information about the image which conclude the singular values that contain negligible amount of information. Hence discarding such values would decrease the size of the image although avoiding noticeable alteration of the original image. The Storage would be represented by the matrix k (m+n+1) units and the integers of k should be less than n. The compression process of image data would preserve in a good resolution and they would not be distorted. Thus, the matrix k integers considered as the storing space that essential for image compressed and the values of k could be adjusted as vectors and calculated for each requirement. The proposed work of Image compression using IIR Filters is illustrated in Figure 4.

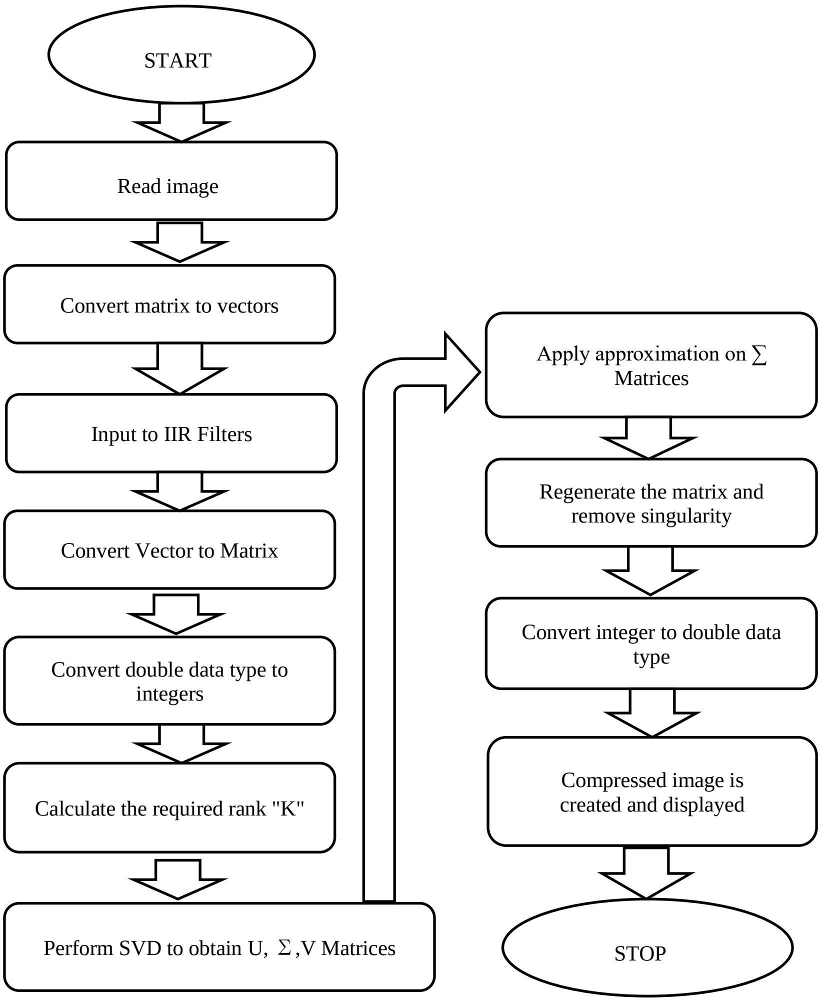

FIGURE 4. **Block diagram of Image compression based on IIR Filters**

The following steps are formalized the process of the proposed work as demonstrated above.

Algorithm 1:
INPUT: Image matrix K
OUTPUT: Compressed matrix k
Steps:

1. Converting the matrix k to vectors of U, ∑, V
2. Insert vectors into IIR Filters
3. Acquire YCBCR from RGB.
4. Produce three vectors for each of the components by applying Input to IIR Filters.
5. Acquire the constituent components Y, CB, and CR from first vector
6. Acquire the middle vector by applying the reconstruction algorithm to the components.
7. Acquire the frequency components for U and V components.
8. Acquire the resultant image using the threshold values of U and V matrices.
9. Last vector is shaped by concatenating the components Y, CB, and CR
10. Return the three magnitude vectors to the original matrix shape.
11. Compute the compression ratio of the final matrix.

The algorithm 1 above is shown with details in the following Figure 5.

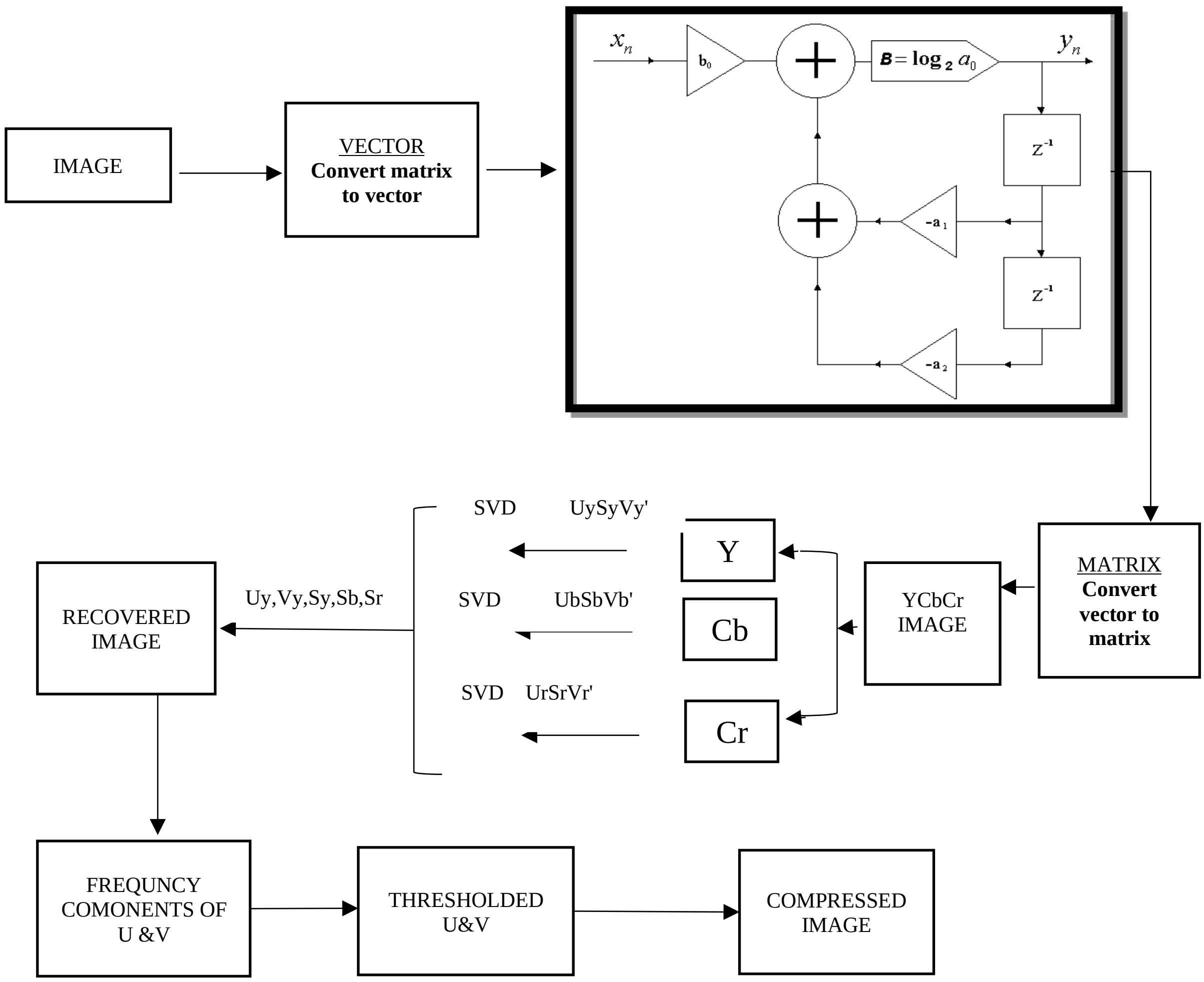

FIGURE 5. The proposed algorithm flowchart

Synthesis of a Bandpass Polynomial IIR Filters

The combination of a polynomial bandpass filter (PBF) of high order of the integers space was examined based on the following necessities:

1. Bandwidth is 0.2 – 0.35 on a qualified frequency scale f/fs
2. The broadcast ratio in the passband 0dB to a tolerance of ± 0.2dB
3. Segment nonlinearity in the band equal or less than 10º
4. The suppression level at occurrences below 0.13 and above 0.42 not less than 40dB
5. Bitness (coefficient word size W_k) 10 bits
6. The polynomial filters instruction are 10
7. The supreme radius of the poles is 0.97
8. Transmission ratios of the units are in the interval (0.8 – 4)

4. RESULTS

The proposed work has been applied in BABY programming plat form. Three images of various sizes where the first image title baby of size 267 kb and another image named Yalta of size 2.29 mb and the last image called sun of size 154kb. They are run via the algorithm, considering diverse number of columns (k) each time. As shown in the following table 1 the Size and the tenacity of output images are evaluated respectively.

5.1 Compression ratio: which represents the ratio of memory that required to store the actual image to the memory. It requires to store a new image computes the extent pixels in the image's compression. It is computed as CR = m×n/(k×(m+n+1)).

Table 1. **Compressed image sizes**

Original image	**Type image**	**size**	**Type image**	**Size**	**Ratio compress(s)**			**the Frobenius norm of matrix or array X**
					10%	%25	%50	n = norm(X,"fro")
baby	png	267 kb	gray	512*512	51.2	128	256	353.4619
yalta	png	1.29 mb	gray	255*255	3.921	63.7	128	259.4099
sun	png	154 kb	gray	128*128	12.8	32	64	58.3345
					SVD Algorithems(D)			n = norm(X,"fro") returns the Frobenius norm of matrix or array X

FIGURE 6. **Compressions for different images**

The above figure 6 represented the experimented pictured that have been processed and compressed based on the proposed algorithm.

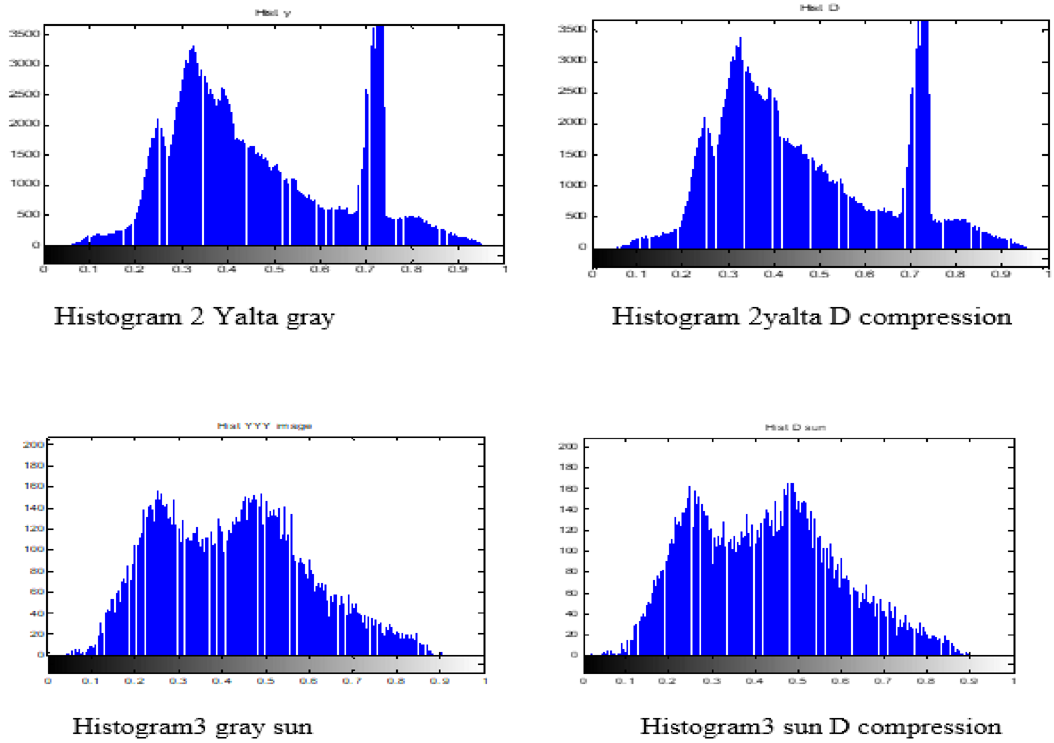

FIGURE 7. **The Histograms for different images**

Figure 7 above illustrated the differences of the original images and compression images that have experimented in the proposed work.

Thus, the objective of the proposed filters was minimized on the 30-dimensional integers space of 10-bit parameters in the acceptable field 15 and filters constraints of 17 on all limits of the transfer models that demanding their radii not to exceed 0.97, and constraints (18) limit the transfer ratios of the filter's segments to the assumed interval. The practical implementation of the filters was executed on the MSP430F1611 multifunction microcontroller with a RISC-core manufactured by Texas Instruments [12]. Individual features of this microcontroller are its low power consumption, low cost, as well as the capability to perform only integer calculations in fixed point format. The frequency response of the filter is measured using a real signal with an automated panoramic measuring system developed in the LabVIEW virtual instrument environment. Experimental graphs of the filter's frequency response for the selection frequency of fs=2 kHz is shown in Fig. 6.

Since, the output signal was taken directly from the microcontroller, some noise level increased which is observed and effected the input signal quantization. The analysis of the output signal at zero input presented that there are no limit rounds with a maximum radius of limits of 0.96. Thus, all the functional requirements for the INP synthesis of a 10-bit recursive IRR filters were met.

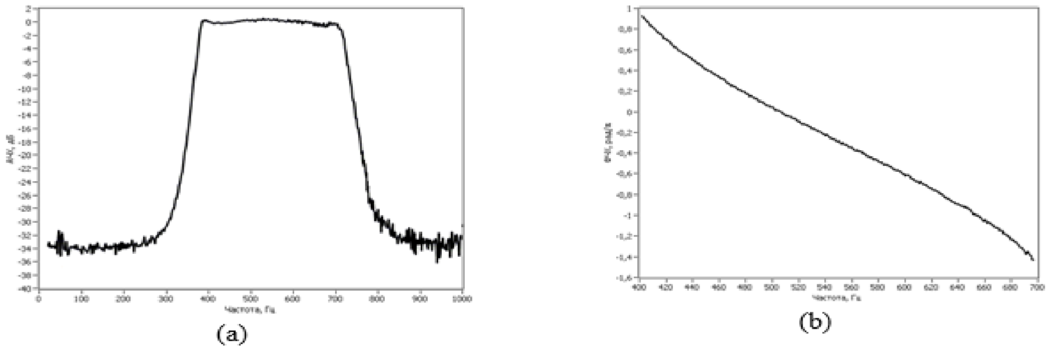

FIGURE 8. Experimental measurement of amplitude-frequency response
(a) and phase-frequency response in the passband (b)

5. CONCLUSION

In conclusion, implementing polynomial IIR digital filters with integer parameters space to compress image data is a powerful approach that enables reducing the size of image files efficiently without losing their quality. The principles of designing IIR digital filters would present new possibilities in the field of image data compression. Reducing the size of image data would making image files smaller and finding the perfect tradeoff among size and quality. From the results it obviously noticed that the proposed method of design polynomial IIR filters for image data compression would contribute in the following:

1.The filters design would be executed in terms of the frequency that characteristics integer parameters detailed in any form.
2.The constancy of the solution for integer parameters of IIR filters is certified through the importance requirements of the functional stability conditions of filters combination. In addition, the proposed method would specify the determined radius of the transfer function that effectively control the integer parameters of IIR filters in the occurrence of any limit rounds.
3.Designing IIR filters would specify the data size directly in the integer filter parameters space.
4.The proposed model determines the high consistency to discover an actual solution of the image data compression extremal problems.
5.The essential advance would be scaling in cascade designs that can be provided directly during the IIR filters synthesis.
6.The polynomial IIR filters would separates the filter coefficients to obtain appropriate integer parameters space. Furthermore, the proposed method produces high performance that may operates in real time and eliminates all restrictions that result from the mathematical computations after implementing polynomial IIR filters on any digital data.

In conclusion, the quality of image data compression is shown that it works efficient and meet the requirements of the proposed IIR filters. The proposed work would help the specialists in the domain of both color image compression and digital signal processing to comprehend the efficiency of IIR filters synthesis. In addition, this work would be helpful for researcher to adapt a complete model with a IIR filters for image data compression. Moreover, the dimensionality reduction characteristics of SVD method would be work efficient for image data compression. In addition, this method improved the effectiveness of using IIR filters in image data compression. This approach would be a new trend for further researchers to make improvements for implementing proper integer parameters initialization to refine the different compression techniques. It considers boundless challenge for researchers to make the compression and transmission of color images more efficient thus various applications would be discovered and many existing applications would be expanded further.

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