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Multi-Algorithm Image Processing Chain Optimization for Efficient and Accurate Image Analysis

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Abstract: In this paper, an algorithm is defined as an ordered set of processes or rules designed to achieve specific objectives. In the context of this study, an algorithm refers to the ordered set of computing processes used to enhance image processing. This research focuses on designing an algorithm for image processing, restricted to a new algorithm that employs cutting-edge techniques in both image processing and computing. The algorithms examined in this study will be limited to those suitable for real-time applications and high-resolution images. The study will compare algorithms, excluding others outside this scope. Performance metrics such as speed, efficiency, and reliability will be key parameters, considered without regard for cases beyond those specified during the algorithm's design. Genetic algorithms, differential evolution, and rank-based uniform crossover are the fundamental features of the two algorithms proposed for optimisation of image processing chains; specifically, LCHF, IPCO, and MIPCO.

Keywords: LCHF, IPCO, MIPCO, Networks, Computing , MATLAB,

1. Introduction

One such method is LCHF, which stands for Local Contrast Hole-Filling Membrane Detection. It can recognise cell membrane structures but cannot identify any organelles. The current aim is to fine-tune the parameters of a pre-defined processing pipeline. Since some parameters are crucial for the algorithms involved, this stage also determines the available parameter ranges for the pipeline to detect cell membranes while ignoring organelles. In its simplest form, LCHF comprises a series of processes starting with preprocessing (denoising and contrast enhancement), followed by classification (threading and hole-filling), and concluding with post-processing (morphology operator smoothing). Each processing stage should have specific parameter settings tailored to the particular data.

The optimization of image processing chain or Image Processing Chain Optimization (IPCO), being the second set of algorithms and their respective test results, and the role of this technique in designing the algorithm, as per the methods provided in the methodology section, is discussed in this chapter as well. This technique is entirely novel, as it builds on the IPCO algorithm, which exploits existing image-processing capabilities. The unique aspect of this algorithm is the "combiner" function, which facilitates image blending by accepting inputs from other functions in the processing chain. MIPCO or Multiple Image Processing Chain Optimization Network, the third and last algorithm discussed in this paper, is included in this chapter as well. Following the procedures explained in the Methodology chapter, this research has played a crucial role in the design of this algorithm and the results of its test have been discussed. Digital images can also be analyzed through identity, authorization, and authentication processes [1]. The content can also be authenticated using fragile or semi-fragile watermarking techniques. Other options that can be considered are the digital signatures and cryptographic algorithms with the use of key distribution that uses the symmetric or asymmetric authentication method. Images can be analyzed for useful data using the Wavelet transform technique [2], where the images are subjected to multi-resolution picture analysis. Understanding the concept of wavelets entails understanding linear algebra and signal processing. The software is used for compression, de-noising, and watermarking. Several Transform image resolutions can be conveyed by wavelets. If there is need for improvement or restoration of the image, or if it needs segmentation for object recognition or compression [3], processes such as those shown below can be considered: In

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the figure above, several digital image processing techniques are used, such as the image acquisition, 2-D signals (images), and the spatial and frequency-domain image enhancement and restoration, image segmentation, and object detection and compression [4].

Simulation is performed using Modalism and MATLAB. The image file is loaded using MATLAB and stored in matrix format. The matrix represents the input. A low-pass filter with a cut-off frequency of π/2 rad/sec acts as an analysis filter [5]. To simplify the process, the image is decomposed into two sub bands. The first sub-band spans frequencies from 0 to π/2 rad/sec, whereas the second sub-band spans frequencies from π/2 to π. Input to the filter is taken in matrix form column by column and the output is stored in text file format.

2. Research Methodology

The process of finding related pixels in an image and movie stills helps provide a condensed version. It shrinks a large image to a more compact form. It identifies features in terms of sudden gray-scale level differences, isolated pixels, lines, and other features using gray-scale level discontinuities. It is applied to locate related features, such as pixel identification in images or movie stills, with the aim of providing a condensed description. This technique will shrink the large image to a more compact form. It can recognise visual features, such as points, lines, and edges, with sudden grey-scale level differences, using grey-scale discontinuity. Thresholding, region growth, region splitting, and region merging can be used to assess the similarity between two images. The partitioning of pictures depends on similarities. Autonomous target acquisition and other computerized analytical methods, like segmentation accuracy, determine whether the technique succeeds or fails. However, it is important in identifying cancer cells and blood vessels in medical images. Using techniques such as thresholding and clustering, it can identify people in surveillance images and movie summaries. Image Segmentation may aid with analysis, interpretation, and pattern recognition when images are joined or broken. When you segment an image, you break it up into smaller, more manageable pieces [6].

The implementation of the aforementioned three methods (LCFH, IPCO, and MIPCO) was evaluated in terms of precision (that is, tp/(tp + fp)), recall (that is, tp/(tp + fn)), and the F1 score (that is, 2 × (precision × recall)/(precision + recall)), wherein tp stands for the number of true positives, fp stands for the number of false positives, and tn stands for the number of true negatives. For each iteration, a confusion matrix was recorded followed by the precision, recall, and F1 scores. The final evaluation values were calculated by taking the average of the results obtained at each iteration of the 30 iterations [7].

Precision, recall, and F1 scores were used to evaluate the performance of the above-mentioned three methods, where tp represents the true positive value and fp represents the false positive value. That is, a confusion matrix and its corresponding precision, recall, and F1 scores were generated for each slice. The performance metrics of each slice out of 30 were averaged to determine the actual performance metrics. As opposed to the arithmetic mean, the F1 score takes the harmonic mean of precision and recall into consideration [8]. For instance, if precision is zero and recall is one, then applying the arithmetic mean will give an accuracy score of 0.5, which equals 50%. On the other hand, the application of harmonic mean will give a score of zero (F1). This indicates that, despite the difference in the denominator of the recall and accuracy scores, their numerators share the same element (true positives). Therefore, the harmonic mean cannot be taken as the average of reciprocals As noted above, precision, recall, and the F1 score were used to measure the performance of the algorithm as follows:

$$\text{Precision} = tp / (tp + fp) \ldots\ldots\ldots\ldots (1)$$

where tp stands for true positive (number of pixels correctly classified to the positive class) and fp represents false positive (number of pixels wrongly classified to the positive class).

$$\text{Recall} = tp/(tp + fn) \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where tp refers to true positives, while fn refers to false negatives (that is, pixels not considered to belong to the positive class but are supposed to do so). False positives include all those pixels that, although wrongly identified as a boundary pixel, actually belong to the interior pixels of a cell according to the ground-truth image. False negatives refer to pixels that were incorrectly identified as interior pixels but are supposed to be boundary pixels according to the ground-truth image.

$$F1 = 2((\text{Precision} \times \text{Recall}) / (\text{Precision} + \text{Recall})) \ldots\ldots \quad (3)$$

The above formula is used to measure the accuracy of the test, where F1 represents the measurement index of the test. Having the highest possible value of 1 and a minimum value of 0, the F1 measure is basically the mean between the recall and precision. Precision, recall and F1 measures for each slice have been calculated after constructing the confusion matrix (3).

In place of the Rand index that heavily penalizes any slight deviation in border placement (as in the ISBI competition), F1 scores were used in this experiment. The calculation of Rand error gives the same value for both false positives and false negatives, depending on the number of pixels related to each object. Likewise, the Warping error was not

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considered here, as it does not affect the data related to non-topological errors. There will be no difference in the quality of the output due to the simple pixel-error measure.

2.1. The Platform: MATLAB and the Image Processing Toolbox

This work was carried out through the exploration calculation process of setting up some important image processing algorithms using MATLAB. MATLAB represents a computer software used in mathematical computations, and image processing represents a toolbox among the most common and important toolboxes available. It is an important toolbox that helps researchers and students who are dealing with image processing [9]. Even though this toolbox assists with image processing, analysis, and visualization, MATLAB is involved in the rapid prototyping processes as well, just like how Microsoft office software is used in offices.

Hardware used in experiments and for creation of the algorithm

Computer Processor	**:**	**Intel Core i3 CPU 2.40 GHz**
Installed memory (RAM)	**:**	**4.00 GB**
System type :		**32 bit Operating System**

3. Performance Analysis Of Algorithm

3.1. LCHF Algorithm Outcome

Algorithm LCHF offers a simple, efficient approach based on LCHF concepts and other essential processing algorithms. Data from TEM Drosophila, which is available from IEEE International Symposium on Biomedical Imaging, proves that LCHF can efficiently detect membrane structures as it takes 21 seconds on average to process 30 slices with an average F1 score of 71%.

Since LCHF produces results without requiring ground truth data, it should be classified as a non-learning algorithm. At the moment, ground truth information has been used only to measure errors [10].

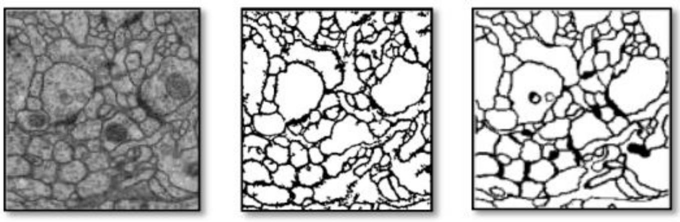

Figure. 1 LCHF Output

3.2. IPCO Algorithm Outcome

Using an ensemble of classifiers is a simple technique to enhance generalization for any classifier. An ensemble of classifiers was used in this work to obtain high F1 scores by including many IPCO chains in an ensemble (selected manually). The average F1 score obtained by the best ensemble of IPCO chains was 92.11%, as shown in the following figure [11].

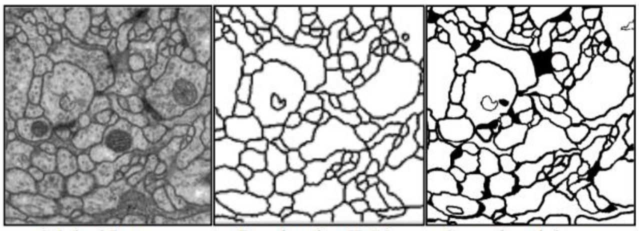

Figure. 2 IPCO Output

3.3. MIPCO Chain Algorithm Outcome

Various sizes and numbers of MIPCO Chains were analyzed through many experiments. It was found that even with only three chains, MIPCO can achieve very high F1 scores (over 91%), which is quite small [12]. The following figures show the smallest MIPCO instances with F1 scores above 91%.

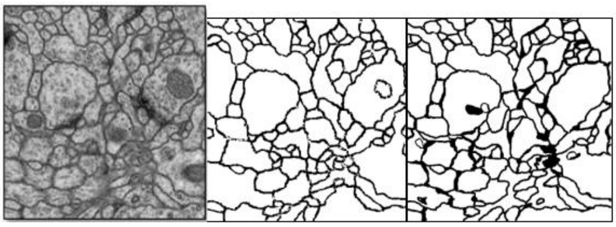

Figure. 3 MIPCO Output

Individual results are shown in Table 1; the mean Recall of 94.50% indicates that classification successfully identified membrane voxels. As for Precision, it got only 89.28%.

Table. 1 Performance score for each slice of the dataset for the score of 91.80%

Image	Precision	Recall	F1 Score
Slice 1	0.897774	0.952891	0.924512
Slice 2	0.9011562	0.937588	0.919011
Slice 3	0.8847477	0.954205	0.918165

Figure 4 shows an example taken from the Wave Scope tool (ISIM simulator), which offers a very effective and user-friendly waveform viewer, allowing the analysis and debugging of the System Generator projects, when the

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time-varying values of any wires of the project after the end of the simulation have been noticed. The signal may appear as a logical or analogue signal and be analysed in binary, hexadecimal, and decimal radices [13]. The figure is taken from the output result of the code executed. The figure comprises two parts: the left side shows the list of parameters, while the right side shows their respective results in relation to the parameters on the left. All these values are in decimals. The RGB value in this case appears as decimal numbers. The simulation is carried out using ModelSim and MATLAB. In MATLAB, an image is read as a matrix. The matrix contains the input data.

Low pass filter with cut off frequency π/2 rad/sec acts as the analysis filter. For simplicity, the image is split into two sub-bands. The sub band 1 contains the frequency range from 0 to π/2 rad/sec and sub band 2 contains the frequency range from π/2 to π. The matrix data is provided as input to the filter column-wise and the output obtained from the filter is saved into a text file [14]. This text file is read by MATLAB software to display the image. The simulation output by the ModelSim tool is shown in Figure.

In the above figure, the first image shows the data out signal from the filter. The filter output is shown as an image using MATLAB. The above figures illustrate the MATLAB output results of the discrete wavelet transform of the input image and the discrete wavelet transform of the sampled image. The down-sampled image is shown in Figure. The sub-band images have smaller size than the actual image.

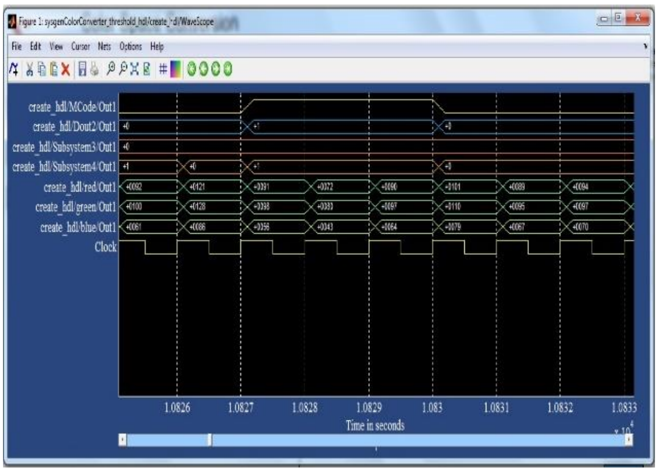

Figure. 4 ISIM viewer

Simulation is performed using Modelsim and MATLAB. The image file is loaded into MATLAB and stored as a matrix. Data is contained within this matrix. A low-pass filter with a cutoff frequency of π/2 rad/sec is employed for filtering. For ease of demonstration, the image is divided into two sub-bands. The first sub-band includes frequencies between 0 and π/2 rad/sec, while the second sub-band covers frequencies from π/2 to π. Matrix data is input into the filter in columns, and the output is saved in a text file [15].

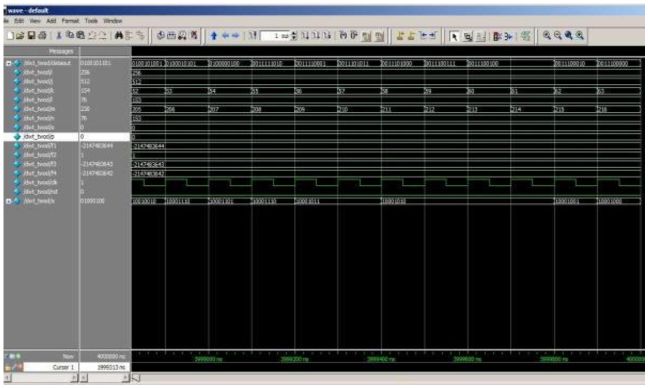

Figure. 5 Simulation Output of Image Processing System

Simulation results of the developed model in Modelsim are shown in the figure. The first waveform is Data Out from the filter. The filter's output as an image, generated using MATLAB, is displayed below in the figure.

The performance of the proposed approach is analysed in comparison to other HDLs such as VHDL, Verilog, and Handel C, focusing on design time, computation time, and program size. As shown in the table, it is evident that Handel C, a hardware description language, provides lower design time, computation time, and programme size compared to the other HDLs [16]. The time required to bring Handel C HDL to the market is shorter and also more cost-effective [17]. Input, as well as Morphological Dilation and Erosion of grayscale images, are illustrated in the figure. Based on the results in the table, it is clear that the resource utilisation in the proposed Handel C HDL is significantly less than in Verilog HDL.

Table. 2 Hardware Resources taken for Verilog and Handel-C

FPGA Resources	VERILOG	HANDEL-C
Speed (Xilinx Spartan 3)	NA	16 MHz
Slices	88 %	15 %
Slice Registers	58 %	4 %
LUTs	56 %	7 %
IOB	10 %	45 %
GCLKs	100 %	55 %
Block RAMs	-	6%
Equivalent Gate Count	308,257	138, 245

The comparative performance analysis of the Spartan 3 FPGA among other FPGAs shows that the output of the suggested FPGA is superior in terms of PSNR, MSE, and AR [18]. The same design is implemented using emulators of various FPGA families.

This study focuses on neuronal membrane recognition, specifically the identification of membranes from organelles. The aim is to develop an efficient, highly accurate algorithm capable of detecting membranes while

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excluding organelles, without requiring labour-intensive processes, and that is easy to use even for novices in the field of Image Segmentation and Classification. Although the literature shows some methods, like genetic algorithms, have been employed, their capabilities are limited. For instance, while the function proposed in this paper offers flexibility in reordering, other approaches require determining the correct order to ensure proper transformation, which can impact speed. Numerous contributions in this area have been made, according to the literature analysed. Compared to other researchers, the algorithms differ mainly in how they optimise and integrate existing functions [19]. The current aim is not to introduce new capabilities for image segmentation but to optimise the use of existing ones to achieve the best results. The proposed framework encourages organisations to develop various representations and transformations, suggesting a completely new pipeline architecture that uses minimal computational and physical resources. When conducting research, it is important to consider hardware limitations and processing time.

Three algorithms have been proposed in this investigation: Local Contrast Hole-Filling (LCHF), Picture Processing Chain Optimization (IPCO), and Multiple Image Handling Chain Optimization (MIPCO). The first algorithm, LCHF, facilitated the development of the second, IPCO, which in turn further advanced the third, MIPCO. The core hypothesis tested in this research is whether basic image processing techniques, combined and adjusted with minimal hardware, can rapidly and accurately distinguish membranes from organelles. Results support this, with the algorithms successfully identifying neuronal membranes and removing organelles using simple image processing techniques with minimal effort, as indicated by the error estimation scores. These scores improve from the first to the third algorithm, reflecting increasing accuracy. Table 7 highlights the achievements of all three algorithms against the research goals. Regarding membrane and organelle differentiation, the LCHF performed well, achieving a maximum accuracy of 71% (Average F1 Score). The second and third algorithms, IPCO and MIPCO respectively, performed more effectively, with average F1 scores of 91.67% and 91.80%. MIPCO provided slightly more accurate results compared to IPCO. While the IPCO algorithm requires significantly less time for optimisation, MIPCO completes network optimisation within seconds per image, amounting to just a few minutes overall.

Therefore, methods like local contrast adjustment, thresholding, noise removal, hole filling, watershed segmentation, morphological processes, and fusion via functions are more appropriate for people who consider precision more important than speed, whereas IPCO is more ideal for those looking for efficiency and speed from their algorithms. Despite its ability to accurately identify all the lines within the membranes, accuracy of output does not guarantee a perfect score because of the differences in membrane thickness.

4. Conclusion and Perspectives: A Visionary Synthesis

The main focus of this study is neuronal membrane identification, with the core test requiring minimal effort and difficulty to identify and remove organelles. This study aims to develop an effective algorithm with extremely high accuracy for identifying membranes and removing unnecessary organelles, requiring minimal effort and being easily available to novices who are not computer experts in Picture Segmentation and Classification. The literature review shows that a set of functions and methods has been used in this research field, including genetic algorithms. However, their capabilities have limitations, as previous studies have indicated. For example, although the suggested algorithm in this study can be reprogrammed to fit the necessary function, other algorithms require channel sequence determination for appropriate manipulation or face difficulties in speed enhancement. Moreover, many Innovations have been made in this area. Compared to other algorithms proposed by researchers in this field, the algorithms developed in this study differ in various aspects of design. This study does not focus on creating innovative capabilities for image segmentation. Instead, it aims to optimise existing capabilities to achieve the best results. The suggested method will motivate chains to create diverse representations and transformations, suggesting that a novel pipeline design is possible that requires little software and hardware resources. Hardware and time constraints must be taken into account when performing this research. The outcome of this investigation is efficient regarding hardware and time.

The research findings will be beneficial for novice researchers, especially those without a background in computer science, and will contribute to the advancement of knowledge by revealing many interesting insights that help design a pipeline for image segmentation. Furthermore, algorithm development enhances basic segmentation capabilities, as the aim of the research is to apply several fundamental processing steps to propose a solution.

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