REVIEW ON APPLICATIONS OF QUANTUM IMAGE PROCESSING

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I, Mohini, 2K19/MSCMAT/30, student of M.Sc. Applied Mathematics, hereby declare that the work which is presented in the Major Project-II entitled **"Review on Applications of Quantum Image Processing"** in fulfilment of the requirement for the award of the Degree of Master of Science in Applied Mathematics and submitted to the Department of Applied Mathematics, Delhi Technological University, Delhi is an authenticate record of my own, carried out during a period from January to May 2021, under the supervision of **Ms. Trasha Gupta.**

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ABSTRACT

Quantum image processing and its various applications developed in the last few years. These applications utilize different quantum algorithms for higher accuracy and reduced time complexity compared to classical computing. This paper reviews some applications of quantum image processing like edge extraction, Security, and denoising of images. Applications like feature extraction, machine vision, and feature detection use edge extraction. In this paper, we observe the field of Security by dividing it into two sub-areas, i.e., cryptography and information hiding, used for authentication purposes. For removal of noise signals from input images, the method of denoising is used.

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1. INTRODUCTION

Image Processing is a field that has a list of varied applications in day-to-day life as well as science and technology. These applications range from remote sensing using satellites for mapping mineral reserves, weather forecasting, and prediction of some natural calamities to medical imaging for treatment and research purposes. It plays a critical role militarily for navigation, surveillance, and target acquisition purposes[1] . To study quantum image processing, we need to look at quantum computing with quantum mechanical systems; the aim is to analyze how information can be represented and communicated using quantum states and how one can secure quantum and classical information using quantum properties like uncertainty, inference, and entanglement. Based on quantum physics principles, in 1982, Feynman proposed quantum computation, a novel computational model[3]. Because of high computational performance and novel algorithms, quantum computation can solve many intractable problems for existing advanced classical computer models and technologies. Quantum technology works based on mathematical formulation and the physical realization that ensures improvement in miniaturization of real-life issues, accelerates specific tasks' performance, and secure communication. In this paper, we discuss Quantum image processing, which is an application of Quantum computing.

To fulfill all the previously stated purposes, we must extract information from the 3D form using image processing. Therefore, we require storing, processing, and retrieval of visual information. Classical computers have restricted architecture and enormous computational complexity, forcing one to find a better and efficient way to utilize visual information. With the evolution of Quantum image processing, we can analyze the problems discussed earlier thoroughly. Qubit lattice, Real Ket, flexible representation of quantum images (FRQI), and novel enhanced quantum representation (NEQR) models are the proposals based on quantum image representations[4]. Since quantum algorithms are more efficient than classical versions, they help in speeding up classical image processing. In quantum computation, all the applied operations must be invertible; therefore, we cannot apply all classical image processing operations to quantum images. Quantum image processing captures, manipulates, and recovers quantum images using quantum computing technologies. QIP(Quantum Image Processing) uses properties like entanglement and parallelism inherited in quantum computation; therefore, QIP can perform tasks that their traditional counterpart technologies are yet unable to perform. This paper gives a brief review of QIP, then stresses the applications of QIP for different purposes like edge extraction, image denoising, security, segmentation and remote sensing.

This research paper is divided into five sections, which are as follows: Section 1 gives a brief introduction of quantum computing and quantum image processing. In Section 2, we discuss related work based on different quantum-based applications. In Section 3, Findings of The Review, all the results after studying related applications are mentioned. Then Section 4 discusses the recent developments in the field of quantum image processing and future scope of applications reviewed and Section 5 gives the conclusion based on our study.

2. RELATED WORK

2.1. Edge Extraction

QSobel[5] is a novel quantum-based image edge extraction algorithm designed using Sobel (classical edge extraction algorithm) and FRQI (flexible representation of the quantum image), which uses the superposition state of a qubit sequence to store all the pixels of an image. FRQI stores each pixel's position information in the ground state of the 2D qubit sequence and the color information in the probability amplitude of a qubit entangled with the qubit sequence. Equation (2.1) expresses the FRQI model.

$$|I> \ = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}(Cos\,\theta_{YX}|0> \ + Sin\,\theta_{YX}|1> \ )|YX> = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}> |YX>$$

(2.1.1)

QSobel Edge Extraction Algorithm

- From Equation(1), it is clear that the FRQI model has a 2D pixel matrix. Now, if the whole image is shifted, then every pixel accesses its neighborhood's information simultaneously.

For an image with size $2^n * 2^n$, **X-Shift transformations**(U(x±)) and **Y-Shift transformations(**U(y±)) unitary operations of FRQI's shift transformations are given by following equations:

$$U(x\pm)|I> \ = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}> |Y> |(X\pm1)mod\,2^n>$$

(2.1.2)

$$U(y\pm)|I> \ = \frac{1}{2^n}\sum_{Y=0}^{2^n-1}\sum_{X=0}^{2^n-1}|C_{YX}> |(Y\pm1)mod\,2^n> |X>$$

(2.1.3)

All pixels of the image will get shifted to left/right neighbourhood pixels in X-axis, and All pixels of the image will get redirected to up/down neighbourhood pixels in Y-axis.

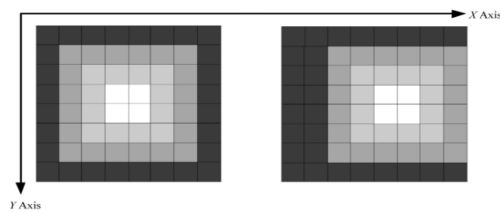

Figure 2.1.1. Transformation U(x+)[5].

Figure 2.1.1 shows the U(x+) transformation operation of FRQI's shift transformations, where every pixel accesses the information of pixels present next to it on the right.

- The application of shift transformation in quantum mechanics is dependent on **Unitary.**

$$\begin{bmatrix} 0^T & 1 \\ I_{2^n-1} & 0 \end{bmatrix}$$

(2.1.4)

When n qubits are used to store X-axis pixel's information, its Transition matrix can be given as:

where, I_{2^n-1}= Identity matrix of size $(2^n - 1) * (2^n - 1)$

$0^T =$ transposed vector of $(2^n - 1)$-dimensional 0 vector.

From Equation(4), $U_{(x+)}U^T_{(x+)} = I$, Hence $U_{(x+)}$ is a unitary matrix[6].

- **Computational Complexity** of any quantum operation is given by the total number of simple quantum gates because we can decompose a multi-qubit operation into simple qubit gates[7].

For constructing the U(x+) transformation circuit, it uses only a single-qubit reversal gate, 2-qubit gate, and 3-qubit Toffoli gate. For an n-length qubit sequence, computational complexity is always less than equal to O(n^2).

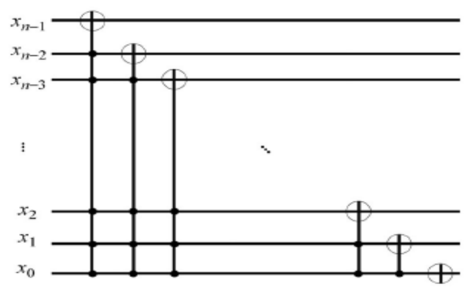

Figure 2.1.2. U(x+) decomposition[5].

Figure 2.1.2 shows the decomposition of a quantum circuit(U(x+) transformation circuit) having length n qubit.

- **Mask Computation** obtains color information of neighbourhood windows using X-shift and Y-shift transformations in a specific order and Sobel masks for the calculation of the intensity gradient of all pixels.

$p(Y-1, X-1)$	$p(Y-1, X)$	$p(Y-1, X+1)$
$p(Y, X-1)$	$p(Y, X)$	$p(Y, X+1)$
$p(Y+1, X-1)$	$p(Y+1, X)$	$p(Y+1, X+1)$

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Figure 2.1.3 Neighbourhood window[5] (left matrix), Sobel masks[5] (middle and right matrix).

Figure 2.1.3 shows the neighbourhood window and sobel masks used for the mask computation.

Intensity gradients mentioned above are calculated according to Sobel masks and neighbourhood windows.

For the calculation of approximate gradient, $U_{\Omega}(\hat{C} \otimes |0>) = \hat{C} \otimes |\Omega(Y, X)>$ is used. Where U_{Ω} is a quantum black box. After the operation of U_{Ω} Sobel gradients computation is complete, it stores these values in $|\Omega(Y, X) >$ representing color qubit. These color qubits entangled with position qubit sequence result in a new output image, where color qubits in edges is equal to |1>, represented by white color. In contrast, other color qubits are |0>, represented by black color.

Limitations: Firstly, FRQI uses the probability amplitude of Qubit to store the color information. It is not easy to obtain the original image without knowledge of exact probability amplitude[8]. Secondly, the whole process must be invertible because all operations in quantum image processing based on FRQI must be unitary. Hence, we cannot perform rotation operations for arbitrary angles[9] and image convolution operation[10].

2.2. Security

Technologies included in quantum image processing-based security are Cryptography(encryption) and Information hiding(Steganography and Watermarking), where cryptography protects message's content and information hiding deals with their existence. Information hiding is more secure as attackers cannot quickly notice it.

In watermarking, authenticating parties study the image for copyright verification. As the amount of pirated data sources is increasing, it becomes essential to have a watermark. Watermarking prevents the original work and encourages future research by giving due credit to the researchers. It hides the information of authenticity in the form of a serial number or some logo. Watermarking is a complex computational problem that needs to be done for every single document for authentication and copyright purposes, therefore with increase in the number of records, the classical methods might not cope with such enormous data. Hence it would be better to switch to quantum techniques for watermarking.

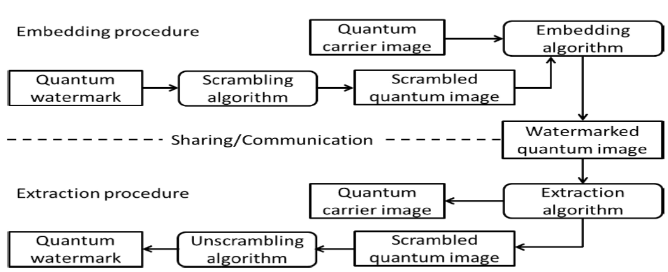

Figure 2.2.1. Algorithm for quantum image watermarking[11].

Figure 2.2.1 explains the Quantum image watermarking Algorithm. This Algorithm embeds the quantum carrier image with a scrambled quantum watermark image. After this, we get a watermarked image as an output. This watermarked image can be shared/communicated by the authority having its copyright. An extraction algorithm is applied to separate the quantum carrier image and the scrambled quantum watermark image for verifying this watermarked quantum image's authenticity. Since the watermarking procedure is reversible, we can extract the carrier image by reversing the embedding procedure.

Encryption is converting the original message into a cipher message for prevention of sensitive information. With the changing world and growth in technology we are switching to digital platforms. We can make online financial transactions, which requires storing the account details. These account details can be attacked by hackers for fulfillment of malicious purposes. To prevent fraud by these hackers is a hefty task for banking institutions. Similarly, a country's military has to keep its data safe from hackers being sensitive and threatening a country’s defence mechanism. In these situations, encryption becomes an essential tool. Encryption is a high computational process and hackers try to break it by performing massive computations. So encryption must be done in a way that the hackers cannot match the level of computation required to break it. Since complex encryption algorithms take considerably longer time to process, using quantum image processing, we can resolve the above-stated issue. Pixel position and pixel value can describe any Quantum image; therefore, we target these two parameters to encrypt quantum images. Scrambling approach(disorder image using pixel position transformation) and replacement approach(altering statistical properties of the original image by conversion of pixel values), these two methods are often used for image encryption in QIP.

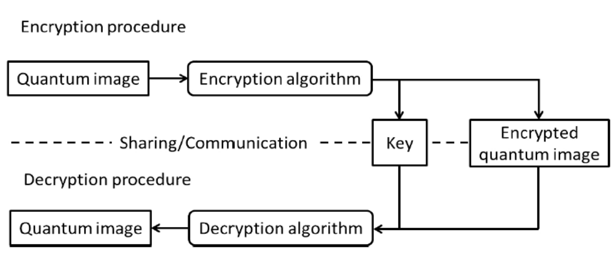

Figure 2.2.2. Quantum encryption algorithm[11].

Figure 2.2.2 explains the encryption algorithm of the quantum image. In this Algorithm, the encryption algorithm encrypts the quantum image; as an output, we get an encrypted quantum image. The decryption algorithm uses a key on the encrypted quantum image to obtain the original quantum image from an encrypted quantum image.

Steganography conceals any secret message with an image without creating any suspicion in the third party's minds. It is not susceptible to any infringements. Steganography is a relatively new field for quantum image processing. The encoded message in a stagnated image should be as short as possible, and it is encrypted so that even if the third party gets suspicious about the content, the message does not break. So to perform this, Quantum computing can be used.

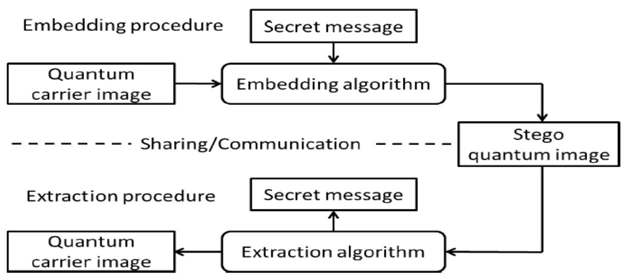

Figure 2.2.3 Quantum Steganography algorithm[11].

Figure 2.2.3 explains the Quantum Steganography algorithm. Here, the steganography algorithm embeds the quantum carrier image with the secret message using an embedding algorithm, and the stagnated quantum image is the output. Stagnated quantum images can be shared over a network. For authenticity verification, any authority can use an extraction algorithm that segregates the secret message and quantum carrier image.

Limitations: The current watermarking practices can be bypassed by cropping, filtering, or adding channel noises. In encryption, if the hacker figures out the pixel value or pixel position disorder algorithm, it can easily be reversed, and encryption fails. In steganography it requires a large carrying capacity in an image to add a secret message.

2.3. Denoising

Image Denoising removes noise from images[12]. For denoising, we can use wavelet transform, Nonlinear filters, Statistical methods, and many more. [13] proposes quantum wavelet transform, which embeds a noisy image into wavelet coefficients(extracted by using fourth-order quantum Daubechis kernel) of the original image.

For processing an image with size $2^n * 2^n$, Daubechies fourth-order wavelet kernel ($D_{2n}^{(4)}$),

$$D_{2n}^{(4)} = (I_{2n-1} \otimes C_1) Q_{2n} (I_{2n-1} \otimes C_0^{'})$$

(2.3.1)

Where, C_1, $C_0^{'}$ are unitary matrices, and Q_{2n} = downshift permutation matrix

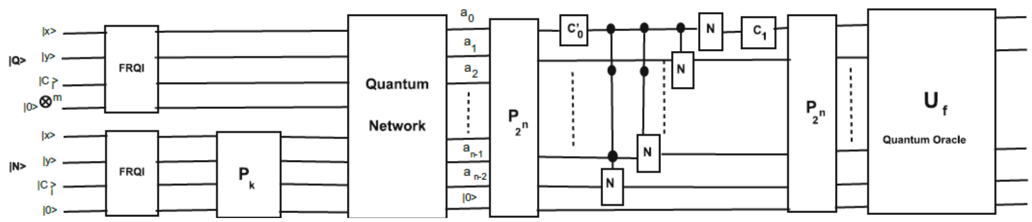

Figure 2.3.1 Quantum circuit for denoising[13].

Figure 2.3.1 explains the quantum circuit used in [13] for noise removal from a quantum image |Q> with size $2^n * 2^n$,

$$|Q> = \frac{1}{2^n} \sum_{i=0}^{2^{2n-1}} (Cos\, \theta_i |0> + Sin\, \theta_i |1>) \otimes |i>$$

(2.3.2)

and the quantum image is stored using the FRQI representation technique. Then an alternate 2n * 2n quantum image with noise called |N> is created by using the FRQI representation technique with a unitary transformation called P_k.

$$|N> = \frac{1}{2^n} \sum_{i=0}^{2^{2n-1}} (Cos\, \theta_i |0> + Sin\, \theta_i |1>) \otimes |i> \quad (2.3.3)$$

$$|P_k> = (I \otimes \sum_{j=0, j \neq i}^{2^{2n-1}} |j> |j>) + R(2\phi_k) \otimes |k> |k> \quad (2.3.4)$$

Where, I is a 2*2 identity matrix and $R(2\phi_k)$ = Rotation operation along z-axis

Unitary transform over the quantum input image |N> is given by the following equation:

$$P|N > \quad = (\prod_{k=0}^{2^{2n-1}} P_k)(|N >) = |PN > \qquad (2.3.5)$$

|PN> is the processed noisy image. After that, we perform QWT($D_{2n}^{(4)}$wavelet transform) to obtain wavelet coefficients QWT |Q> .

$$QWT(|Q >) = QWT(\frac{1}{2^n}\sum_{i=0}^{2^{2n-1}}(Cos\,\theta_i\,|0 > \;+\; Sin\,\theta_i\,|1 >)\otimes|i >) = \sum_{i=0}^{2^{2n-1}}|wc_i > \otimes|i >$$

(2.3.6)

QWT(|QN>) gives qubits after embedding quantum noisy image and wavelet coefficients,

$$QWT(|QN >) = QWT(|Q >+ \;|P_k N >) = \sum_{i=0}^{2^{2n-1}}|wmc_i > \otimes|i >$$

(2.3.7)

It uses the inverse of QWT and inverse of P_k^{-1} to get the noisy image states that are extracted from the quantum image after embedding. Final extracted noisy image is given by:

$$|N > \quad = P_k^{-1}[QWT(|QN >) + QWT(|Q >)] \qquad (2.3.8)$$

Since Fourier transforms and wavelet transforms are unitary, therefore quantum counterparts can be used extensively for image denoising. [13] produces favorable outcomes and has more accuracy in detection with fewer features than classical image denoising methods. The time complexity of the proposed methods is less than many existing popular methods. Quantum Wavelet Transform is a revolutionary technique, and it is the first of its kind. [13] compares the classical and quantum-based algorithms to understand the result better, which is the uniqueness of this paper. The results confirm the fact that QIP has far less computational complexity than the classical.

Limitations: Quantum Wavelet transform can only be used in quantum image processing because it is a unitary operation. We cannot use any non-unitary operation in quantum computing and the research work in this field is still in its infant stage and has not been tested thoroughly with all test cases. Also, quantum computers are not available everywhere, so parallel processing on classical computers will be positive.

3. FINDINGS OF THE REVIEW

What is Quantum Computing?

Quantum computing uses quantum concepts like superposition and entanglement. The use of quantum computing is increasing mainly due to the increase in the complexity of computation. As the computations increase, it becomes difficult for classical computers to make such computations. Many computer problems require extensive calculation, such as encryption or any NP problem. The solutions for NP problems are verifiable by the computer, but they are not solvable. Quantum computing reduces the exponential time complexity required for solving NP problems. As in physics, quantum mechanics is much more complex and broad than classical mechanics, the same as quantum computing. Indian government is planning to set up a quantum lab with Amazon. Quantum computing is attracting big tech giants like Google, Amazon, IBM, and many more. This field is in early stages and is mainly used for research work. It will take time to build such machines that can perform these tasks for commercialization, but it will reduce the time and space once it is done. In classical, bits can have either of two values, 0 or 1. Qubits in Quantum computing are analogous to bits in classical computing. An atom can represent the state of Qubit.

One benefit of QIP over CIP(classical Image processing) is that QIP can directly use any image without preprocessing. In CIP image loses some of the information while storing it; this is not the case with QIP. In QIP, the image representation has both color values (or gray-scale) and corresponding pixel locations of an image using the quantum registers' concept. Quantum gates measure the performance of QIP; the computational complexity increases with the increase in the number of quantum gates.

Table 3.1. Quantum image representations[14]。

Representative representations	**Description**	**Drawbacks**
Qubit Lattice	One qubit state's probability amplitude is used to encode the color information, but encoding of position information is not explicitly done by qubits	In image processing, the task of position information controlling is difficult .
FRQI	For an image of size $2^n * 2^n$, encoding of color information is same as the qubit lattice, and position information is encoded in 2n qubits	Since probability amplitude is used to store the color information, infinite measurements are required for getting accurate probability so that quantum images can be converted into classical form.
NEQR	For an image of size $2^n * 2^n$, multiple qubit basis are used to store the color information, and position information is encoded in 2n qubits	similar to FRQI

Table 3.1 gives a brief description of some quantum image representation models with their drawbacks.

In [5], the authors compared the performance of QSobel with other edge extraction algorithms. They considered an image of size $2^n * 2^n$. For any FRQI quantum image, the QSobel algorithm extract edges O(n^2) computational complexity.

Table 3.2. Comparisons between different quantum image edge extraction algorithms.

Algorithm	Quantum image model	Complexity of quantum image construction	Complexity of edge extraction
Sobel	-	-	O(2^{2n})
Prewitt	-	-	O(2^{2n})
Canny	-	-	O(2^{2n})
Tseng	Qubit lattice	O(2^{2n})	O(2^{2n})
Fu	Qubit lattice	O(2^{2n})	O(2^{2n})
Fan	NEQR	O($qn2^{2n}$)	O($n^2 + q^2$)
Fan	NEQR	O($qn2^{2n}$)	O($n^2 + 2^{q+4}$)
QSobel	FRQI	O(2^{4n})	O(n^2)

Note: Above comparison is done for a digital image having a size 2n × 2n [5, 15].

Table 3.2 gives a comparison between edge extraction algorithms. For classical algorithms, this table gives the time complexity of edge extraction. While for quantum based algorithms, it gives the quantum image model used, complexity of quantum image construction, and complexity of edge extraction. It shows that the edge extraction complexity of quantum based algorithms is much better than classical algorithms.

Table 3.3. Security Schemes[11].

Scheme/quantum circuit (Security technology)	Description

WaQI (Watermarking)	Cover and watermark images are used; for random hiding of watermarks in the carrier image, a watermark embedding circuit is produced.
QFT (Watermarking)	For the extraction of watermarking image quantum Fourier transform was used
MC-WaQI (Watermarking)	MCQI representation used with WaQI in place of FRQI representation helped in better protection of colored quantum image against malicious attackers
Arnold and Fibonacci scrambling quantum circuit (Encryption)	For scrambling image, this quantum circuit uses plain adder and addition modulo N on input quantum image and output quantum image
Hilbert scrambling quantum circuit (Encryption)	Recursive generation algorithm is used to generate a Hilbert scanning matrix
Moire pattern (Steganography)	Any binary image can be hidden into any grayscale image by using this algorithm
LSQb (Steganography)	A qubit stream of secret message is embedded into the ending qubits of color information of carrier quantum image

Table 3.3 gives a brief description of some quantum based security schemes used in [11]. The schemes given in this table are used for watermarking, encryption, and steganography.

In [13], for denoising of a quantum image, Quantum wavelet transform is used in the Algorithm. For this purpose, a quantum image with size $2^n * 2^n$ is used, which uses 2n+8 qubits for storage on the FRQI image model. The quantum image construction complexity is O(2^{4n}), which is far less than other denoising algorithms.

4. RECENT DEVELOPMENTS AND FUTURE SCOPE

Image processing has many applications. We can apply quantum image processing to store medical images such as MRI, CT scan, or X-rays in the medical field. [16] proposes Opti-QIBDS Net, a quantum-based neural network architecture used for automatic segmentation of brain MRI. [17] uses feature extraction technique based CNN applied on a set of X-rays containing infected and non-infected, and detects pneumonia. Opti-QIBDS Net can be used in place of CNN for pneumonia detection for more efficiency. Presently, the world is facing the pandemic COVID-19. This pandemic has a devastating impact on the healthcare sector across the globe.

To deal with this and prepare ourselves for the worst situations like these in the coming future, we must find alternative methods for faster results. Since CT scans and X-rays are used to detect COVID-19, similar to pneumonia detection, Opti-QIBDS Net[16] can be used. Multilevel Thresholding is a popular image segmentation technique. [18] proposes quantum-behaved PSO(Particle Swarm Algorithm) for tackling the problem of dimensionality and computation time. In [19, 20], based on decision fusion, the authors proposed an object-based method for classification remote sensing images. Both [19, 20], use segmentation before the classification of homogeneous regions in the remote sensing image.

In future research, researchers can use the method proposed in [18], the method based on quantum; this would reduce the computational complexity required for segmentation. In [5, 21], authors have given improved versions of existing edge extraction operators in quantum; in a similar direction, further research work can be done for improving other classical operators with the use of quantum. After this, we can compare the performance and efficiency of these quantum-based operators. This would give the best results possible. The quantum computing concept can help build smaller electronic devices with higher efficiency and effectiveness in doing high computations. In our opinion, we need to commercialize the field of quantum computing. By doing this, big tech giants would compete for better profit which in turn would help in the growth of the field of quantum computing. Due to the lack of availability of quantum computers, many researchers are unable to apply their ability, which acts as a barrier in the development of quantum-based applications. For removing this barrier, many companies have set up labs; these labs can be accessed online. Future researchers can access these labs; this would help them develop and contribute to the quantum computing field.

5. CONCLUSION

With the boom in the digital platform, digital data is increasing day by day. With this increase, we need to increase our computational strength. By using quantum computing, we can easily outperform some existing classical computing algorithms by a considerable margin. Quantum image processing is in its infant stages. This field must be explored further because of their enormous scope for betterment. In [5], QSobel is designed by combining FRQI(quantum image model) and Sobel(edge extraction algorithm), have a computational complexity of O(n^2), and [13] shows that Daubechies quantum wavelet kernel used has construction complexity of O(2^{4n}) which shows exponential improvement in both the field of edge extraction and denoising of the image respectively. Since there is a sharp increase in image data available today, Security has become our primary concern. Therefore, for moving data offline to online safely, reducing energy and saving time must be our aim in further research while focusing on designing novel quantum algorithms that can improve quantum algorithms and deal with the deficiencies that might be introduced due to being a drawback in existing algorithms.

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Acceptance Notification

The 13th International Conference on Digital Image Processing

- *Paper ID: CD0105*
- *Paper Title: Review on Applications of Quantum Image Processing*
- *Authors: Mohini and Trasha Gupta*

To whom it may concern,

Congratulations!

Based on the reviewer's comment and recommendation, we are glad to inform that the paper identified above is accepted for presentation and publication. Accepted papers after proper registration and presentation will be published in the **conference proceedings by SPIE**, which will be included in **SPIE Digital Library** and indexed by **Ei Compendex, Scopus,** etc. The previous twelve proceedings have been successfully indexed by Ei Compendex and Scopus.

ICDIP 2021 offers a rich program, including keynotes speeches, peer-reviewed paper presentations, panel discussion, round table discussion, city tour, etc. We are accepting paper submissions, poster presentation submissions, and listener registrations. Whether you want to share the findings of your latest research with the international group of peers or learning from fellow researchers, scientists, and scholars, we can't wait to see you Singapore.

On behalf of the organizing committee, we are cordially inviting the authors to attend the conference and present the paper at ICDIP 2021 in **Singapore** during **May 20-23, 2021**. Please complete the registration procedure before **May 05, 2021**. See below the registration procedure please.

We're looking forward to meeting you in Singapore!

As your safety is our top priority and concern, the conference has added online attendance / presentation for participants in case of you cannot attend the conference because of the COVID-19.

Yours sincerely,

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19/05/2021

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Final Paper Submission

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Multimedia Tools and Applications (Electronic ISSN: 1573-7721; Print ISSN: 1380-7501)
Impact factor: 2.313 (2019)
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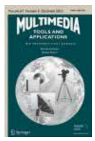
Abstracted and indexed in: Science Citation Index Expanded (SciSearch), EI Compendex, Scopus, ACM Digital Library, CNKI, DBLP, etc.



Important Dates

Submission Deadline	April 15, 2021
Notification Deadline	April 30, 2021
Registration Deadline	May 5, 2021

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