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Quantum Image Teleportation Protocol (QITP) and Quantum Audio Teleportation Protocol (QATP) by using Quantum Teleportation and Huffman Coding

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***Abstract*—In order to transmit images and audio securely, the authors present the Quantum Image Teleportation Protocol (QITP) and Quantum Audio Teleportation Protocol (QATP), which utilizes the Quantum Teleportation (QT) technique combined with Huffman Coding. The QITP secures the teleportation of quantum states of an image while simultaneously encrypting and decrypting them using Huffman Coding since it is only possible to recover or decode data if the prefix codes are known. To test their approach, the authors transformed pixels or RGB values from digital images into text, which was then fed into the Huffman Coding Technique. It has the advantage of compressing the entire text, which makes it faster to transmit vast amounts of information. This work also demonstrates the Quantum Audio Teleportation Protocol (QATP) with and without Huffman coding. For proof of concept, experimental evaluations were performed for both suggested QITPs and QATPs (Standard QITP, QITP with Huffman Coding, Standard QATP, QATP with Huffman Coding), using IBM Quantum Assembly Language (IBM QASM) Simulator and real quantum hardware using the Quantum Information Science Kit (Qiskit), a quantum computing platform.**

***Index Terms*—Quantum Computing, Huffman Coding, Quantum Information Science Kit, Quantum Teleportation, ASCII, Sampling rate, Time-series, mono/stereo, Prefix codes**

I. Introduction

Quantum entanglement [1] is required for quantum teleportation (QT) [2]–[4], quantum key distribution (QKD) [5], [6], distributed quantum computation [7], quantum networks [8]. The QT method, an integral part of quantum entanglement, uses shared entangled states between the sender and the receiver as well as classical communications and local operations to transmit quantum information stored in an unknown quantum state from one location to another [4]. The QT approach allows us to transport just the quantum state of information from one qubit (Alice, the sender) to another qubit (Bob, the receiver), which are entangled and separated by an intermediate qubit (Telamon). An arbitrary single-qubit state can be transmitted to a distant destination using a Bell state maximal entanglement developed by Bennett *et al.* [4]. There is a lot of attention paid both theoretically [9]–[14] as well as experimentally [15]–[20].

To the best of the authors' knowledge, this is the first study to successfully demonstrate teleportation of quantum states of image and audio files using the suggested Quantum Image Teleportation Protocols (QITP) and Quantum Audio Teleportation Protocols (QATP) respectively based on two principles: QT method and Huffman Coding.

The rest of the paper is structured as follows: Section II-A explains in details the proposed Standard QITP and QITP with Huffman Coding. The QATP with and without Huffman Coding are also discussed in Section II-B. Section III examines an evaluation study of both suggested QITPs and QATPs for teleporting quantum states of secure image and audio transfers utilising IBM Quantum Simulator and actual quantum hardware via IBM Quantum Experience (IBM QX) [21]. This is followed by conclusion and future works in Section IV.

II. Proposed Quantum Image Teleportation Protocols (QITPs) and Quantum Audio Teleportation Protocols (QATPs)

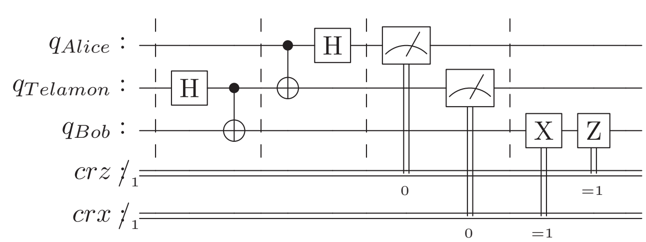

Fig. 1. Quantum Circuit of QT Technique that is employed for demonstration of both of the Proposed QITPs and QATPs [2]

The quantum circuit in Fig. 1 will be used for demonstrating the successful quantum teleportation of images and audio files for both of the proposed QITPs (Standard QITP and QITP with Huffman Coding) and QATPs (Standard QATP and QATP with Huffman Coding).

The steps that are to be followed for QITPs and QATPs are explained in the following.

A. *Proposed QITPs*

*1) **Standard QITP**:* The Standard QITP or QITP without Huffman Coding teleport the quantum state of an image from

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the sender (Alice) to the receiver (Bob) that are physically separated from each other using the QT technique presented in Fig. 1. This protocol can teleport quantum state of each RGB value of a pixel of the image.

This protocol may be executed with as few as three qubits, one for Alice, Bob, and Telamon, exploiting quantum superposition principles, generally it takes longer to teleport quantum states when utilizing three qubit.

The steps that need to be followed in order to teleport the quantum state of a digital image using the Standard QITP can be explained in details as follows:

a) ***Step I****:* The first step is to read an image input with any extension (.png, .jpg, .jpeg, .ppm, .tif etc.), and convert the image to its respective RGB format, followed by the extraction of RGB values from the pixels.

b) ***Step II****:* The second step is to convert each RGB value to binary format, ensuring that each value corresponds to eight-bit binary string.

c) ***Step III****:* The binary strings are then accessed as a single binary string, divided into sub-binary strings based on the number of qubits available for Alice, Bob, and Telamon, and the quantum state of each binary value is transferred to the quantum teleportation circuit (Fig. 1).

d) ***Step IV****:* The receiver (Bob) can obtain the quantum state of the binary string after it has been successfully teleported, which can then be converted back into RGB values of each pixel of the image and save it in native image format.

2) ***QITP with Huffman Coding****:* The second image teleportation protocol uses QITP with an additional encoding technique known as Huffman Coding, teleporting the quantum state of binary data using a minimum of three qubits, where each binary sub-strings of compressed binary string is being communicated at once. Due to the fact that the compression of text files using the Huffman Coding method was employed, the conversion of images into text files using pixels and their equivalent RGB values was performed firstly. In order to avoid ambiguity during pre- and post-processing of pixels, the appending of additional ASCII characters were also performed.

After successful teleportation, the data is decompressed again to retrieve the original text content. The quantum state of binary data is transported through QITP with Huffman Coding if both Alice and Bob have the prefix codes. A text file is transformed into an image at the receiving end after it has been successfully sent.

Due to the fact that QITP with Huffman Coding utilizes more characters, data transport takes longer than when QITP is used in its standard format. The greatest benefit of employing QITP with Huffman Coding is the increased security, which is the most important requirement for any data transfer mechanism.

Following are the steps that need to be followed in order to teleport the quantum state using QITP with Huffman Coding:

a) ***Step I****:* The first step is to read an image input with any extension (.png, .jpg, .jpeg, .ppm, .tif etc.), and convert the image to its respective RGB format, followed by the extraction of RGB values from the pixels.

b) ***Step II****:* The second step is to convert each RGB value to binary format, by converting to its corresponding eight-bit binary string per RGB value of each pixel and store it in a text file. During the conversion process, the addtion of some extra characters takes place in order to determine which value corresponds to which RGB value and which RGB value belongs to which pixel.

c) ***Step III****:* The third step is to determine the frequency of each character, that is, how often the character appears in the whole text file and generate the prefix codes for each character using Huffman Coding.

d) ***Step IV****:* Each of these prefix codes determines how the text file should be rewritten using the same prefix codes. The entire text file is then written using the prefix codes and saved in an ".bin" extension file.

e) ***Step V****:* The next step is to access the binary strings as a single binary string and then, based on the number of qubits available for Alice, Bob and Telamon, the binary string are partitioned into sub-binary strings.

f) ***Step VI****:* Next, the successful teleportation of quantum state of binary sub-strings is performed through the quantum circuit (Fig. 1).

g) ***Step VII****:* Assuming that the sender (Alice) and the receiver (Bob) already know the prefix codes, the binary sub-strings are translated back to characters, and stored in the native text format by removing extra special characters that were added at the sender (Alice's) end.

h) ***Step VIII****:* Next, the characters are then converted back to integers (either of 0 to 255 values) and then to its corresponding RGB values of each pixel of the image to produce the digital image at the receiver end.

B. Proposed QATPs

1) ***Standard QATP****:* The Standard QATP or QATP without Huffman Coding teleport the quantum state of an audio sample from the sender (Alice) to the receiver (Bob) using the QT technique presented in Fig. 1. The steps followed for both the QATPs are as follows:

a) ***Step I****:* The first step is to read an audio sample file, and then, convert into a time-series mono/stereo channel sample with a sampling rate of 22050 Hz (by default).

b) ***Step II****:* Since, there will be both positive and negative numbers in the array of audio sample, the conversion of negative numbers to positive numbers are done by adding the absolute value of the most negative number of the array and one (i.e. $|value_{minimum}| + 1$) to all the values in the array. Thus, this convert all negative numbers to positive numbers. At the end, the final array is a positive-valued array.

c) ***Step III****:* The next step is to convert each value (of the array) into a binary string by adding an extra special character that function as a separator between each values in the binary format.

d) ***Step IV****:* The binary strings are then accessed as a single binary string, divided into sub-binary strings based on the number of qubits available for Alice, Bob, and Telamon, and the quantum state of each binary value is transferred to the quantum teleportation circuit (Fig. 1).

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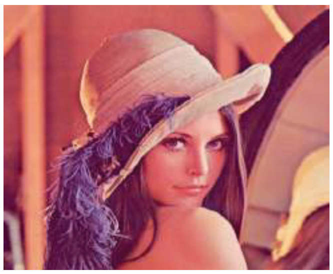
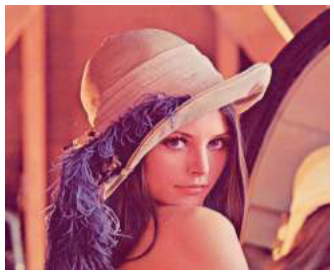
(a) cameraman.tif (512 × 512)


(b) house.tif (512 × 512)


(c) jetplane.tif (512 × 512)


(d) lake.tif (512 × 512)

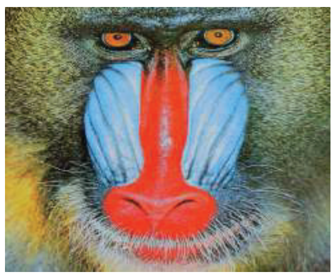

(e) lena_color_256.tif (256 × 256)


(f) lena_color_512.tif (512 × 512)

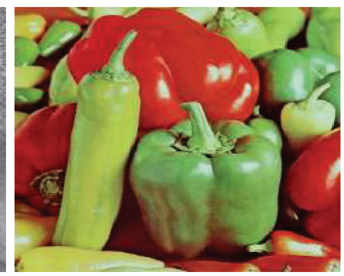

(g) lena_gray_256.tif (256 × 256)


(h) lena_gray_512.tif (512 × 512)


(i) livingroom.tif (512 × 512)


(j) mandril_color.tif (512 × 512)


(k) mandril_gray.tif (512 × 512)


(l) peppers_color.tif (512 × 512)


(m) peppers_gray.tif (512 × 512)


(n) pirate.tif (512 × 512)


(o) walkbridge.tif (512 × 512)


(p) woman_blonde.tif (512 × 512)

Fig. 2. Benchmarks Camera Images Dataset [22]

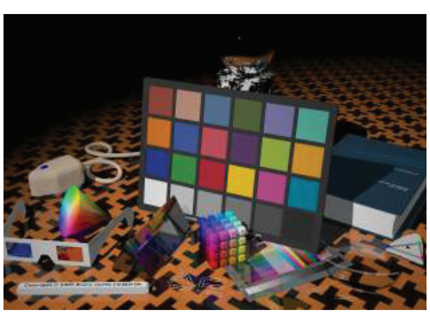


Fig. 3. High Resolution Sample Image from reference Dataset [23]: artificial.ppm (3072 × 2048)

e) ***Step V****:* The receiver (Bob) can obtain the quantum state of the binary string after it has been successfully teleported, which can then be converted back into floating-point numbers of the array by removing the special character added as the separators. Next, the added absolute value of the most negative value of the array by the sender (Alice) is removed by the receiver (Bob) which is already known, and finally saved it in an array. This is then converted back to the audio sample at the receiver end.

2) ***QATP with Huffman Coding****:* This proposed QATP in conjunction with Huffman Coding enables shorter teleportation times while requiring fewer qubits.

Following are the steps that need to be followed in order to teleport the quantum state of text file using the QATP with

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Huffman Coding:

*a) **Step I**:* The first step is to read an audio sample file in any format (.wav, .mp3, .mpeg etc.), and then, convert into a time-series mono/stereo channel sample with a sampling rate of 22050 Hz (by default).

*b) **Step II**:* The second step is to convert the array into only positive values and then saving it in a text file where each value is separate by a special character to remove ambiguity at receiver end.

*c) **Step III**:* The third step is to determine the frequency of each character, that is, how often the character appears in the whole text file.

*d) **Step III**:* The next step is to generate the prefix codes for each character using Huffman Coding.

*e) **Step IV**:* Each of these prefix codes specifies how the text file should be rebuilt using the same prefix codes. The entire text file is then recreated using the prefix codes and saved in a ".bin" extension file.

*f) **Step V**:* The binary strings are then accessed as a single binary string and then partitioned into sub-binary strings for Alice, Bob, and Telamon based on the number of qubits.

*g) **Step VI**:* Next, the successful teleportation of quantum state of binary sub-strings is performed through the quantum circuit (Fig. 1).

*h) **Step VII**:* Assuming that the prefix codes are already available to the sender (Alice) and the receiver (Bob), the binary strings are converted back to characters and saved into the native text format, by removing extra special characters that were added at the sender (Alice) end.

*i) **Step VIII**:* This is further stored into an array to convert it back to the audio sample file which is the original audio sample to be received at Bob's end.

III. Evaluation Study of Proposed QITPs and QATPs

Both of the proposed QITPs and QATPs for demonstration on sample image and audio files are simulated on IBM Quantum simulator [21] first, and then on real quantum hardware [27].

A. Sample Test Images

The sample test images taken as input images for both the proposed QITPs are from the reference benchmarked camera datasets [22] and are also shown in Fig. 2. The data sets includes sixteen .tif images of different image sizes (256×256 and 512×512) including colour-scale and gray-scale images from benchmarked camera datasets. One high-resolution image was also taken as the sample image from the data set [23] (Fig. 3) to verify high-resolution images for quantum teleportation using the proposed QITPs.

B. Sample Audio Files

The sample audio files taken as input audio files for both the proposed QATPs are from the reference links ([24], [25] and [26]). The three samples audio files include .wav, .mp3 and .mpeg files are used to verify audio transportation using the proposed QATPs.

TABLE I

Evaluation Study On QISKit Simulator demonstrating the Proposed QITP techniques and showing Trade-off between No. of qubits and No. of Iterations

Image Data Sets [22], [23]	No. of Qubits	**No. of Iterations**	
		Standard QITP	**QITP with Huffman Coding**
cameraman.tif [22]	24	7,86,432	11,75,634
(512 × 512)	12	15,72,864	23,51,268
	6	31,45,728	47,02,536
	3	**62,91,456**	**94,05,072**
house.tif [22]	24	7,86,432	12,19,956
(512 × 512)	12	15,72,864	24,39,912
	6	31,45,728	48,79,824
	3	**62,91,456**	**97,59,648**
jetplane.tif [22]	24	7,86,432	12,66,206
(512 × 512)	12	15,72,864	25,32,412
	6	31,45,728	50,64,824
	3	**62,91,456**	**1,01,29,648**
lake.tif [22]	24	7,86,432	12,09,793
(512 × 512)	12	15,72,864	24,19,586
	6	31,45,728	48,39,172
	3	**62,91,456**	**96,78,344**
lena_color_256.tif [22]	24	1,96,608	3,04,757
(256 × 256)	12	3,93,216	6,09,514
	6	7,86,432	12,19,028
	3	**15,72,864**	**24,38,056**
lena_color_512.tif [22]	24	7,86,432	12,19,351
(512 × 512)	12	15,72,864	24,38,702
	6	31,45,728	48,77,404
	3	**62,91,456**	**97,54,808**
lena_gray_256.tif [22]	24	1,96,608	3,06,932
(256 × 256)	12	3,93,216	6,13,864
	6	7,86,432	12,27,728
	3	**15,72,864**	**24,55,456**
lena_gray_512.tif [22]	24	7,86,432	12,27,794
(512 × 512)	12	15,72,864	24,55,588
	6	31,45,728	49,11,176
	3	**62,91,456**	**98,22,352**
livingroom.tif [22]	24	7,86,432	12,16,217
(512 × 512)	12	15,72,864	24,32,434
	6	31,45,728	48,64,868
	3	**62,91,456**	**97,29,736**
mandril_color.tif [22]	24	7,86,432	12,04,977
(512 × 512)	12	15,72,864	24,09,954
	6	31,45,728	48,19,908
	3	**62,91,456**	**96,39,816**
mandril_gray.tif [22]	24	7,86,432	12,27,063
(512 × 512)	12	15,72,864	24,54,126
	6	31,45,728	49,08,252
	3	**62,91,456**	**98,16,504**
peppers_color.tif [22]	24	7,86,432	11,63,556
(512 × 512)	12	15,72,864	23,27,112
	6	31,45,728	46,54,224
	3	**62,91,456**	**93,08,448**
peppers_gray.tif [22]	24	7,86,432	11,77,079
(512 × 512)	12	15,72,864	23,54,158
	6	31,45,728	47,08,316
	3	**62,91,456**	**94,16,632**
pirate.tif [22]	24	7,86,432	12,01,706
(512 × 512)	12	15,72,864	24,03,412
	6	31,45,728	48,06,824
	3	**62,91,456**	**96,13,648**
walkbridge.tif [22]	24	7,86,432	11,97,919
(512 × 512)	12	15,72,864	23,95,838
	6	31,45,728	47,91,676
	3	**62,91,456**	**95,83,352**
woman_blonde.tif [22]	24	7,86,432	12,27,155
(512 × 512)	12	15,72,864	24,54,310
	6	31,45,728	49,08,620
	3	**62,91,456**	**98,17,240**
artificial.ppm [23]	24	1,88,74,368	2,27,24,802
(3072 × 2048)	12	3,77,48,736	4,54,49,604
	6	7,54,97,472	9,08,99,208
	3	**15,09,94,944**	**18,17,98,416**

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TABLE II
EVALUATION STUDY ON QISKIT SIMULATOR DEMONSTRATING THE PROPOSED QATP TECHNIQUES AND SHOWING TRADE-OFF BETWEEN NO. OF QUBITS AND NO. OF ITERATIONS

Audio Files	No. of Qubits	No. of Iterations	
		Standard QATP	**QATP with Huffman Coding**
pinkpanther30.wav [24]	24	52,20,219	22,62,991
	12	1,04,40,438	45,25,982
	6	2,08,80,876	90,51,964
	3	**4,17,61,752**	**1,81,03,928**
sample.mp3 [25]	24	47,96,924	21,03,429
	12	95,93,848	42,06,858
	6	1,91,87,696	84,13,716
	3	**3,83,75,392**	**1,68,27,432**
its my life.mpeg [26]	24	79,55,140	34,76,699
	12	1,59,10,280	69,53,398
	6	3,18,20,560	1,39,06,796
	3	**6,36,41,120**	**2,78,13,592**

C. Experimental Results

*1) **On IBM Quantum Simulator**:* By using ”32-qubit IBM QASM simulator”, the binary data from the input file was transferred directly to the quantum circuit, which was run for different numbers of qubits: 24, 12, 6 and 3 with Alice, Bob and Telamon all having 8 qubits, 4 qubits, 2 qubits and 1 qubit, respectively. Once the quantum teleportation was successful, the same binary list of elements was obtained as output at the receiver (Bob) end.

*2) **On IBM Real Quantum Hardware**:* Since the present quantum hardware provided by IBM is currently available with only five qubits for free public access, experiments were conducted using only three qubits: one each for Alice, Bob, and Telamon (Fig. 1). The quantum state of binary elements was teleported directly from the input binary data, and after successful teleportation, the same binary list ware obtained at the receiver end.

Table I shows evaluation study of both of the proposed QITPs and summarizes how the total number of qubits used by Alice, Bob and Telamon results into variation in the number of iterations for teleporting the quantum state of Benchmarks Camera Images Dataset (Fig. 2) and a high-resolution image (Fig. 3). Also, Table II shows evaluation study of both of the proposed QATPs and summarizes how the total number of qubits used by Alice, Bob and Telamon results into variation in the number of iterations for teleporting the quantum state of audio sample files ([24]–[26]).

Note: The entire quantum experiment on real quantum hardware are based solely on counts, not on probabilities.

D. Discussions

The Standard QITP and the Standard QATP do not require prefix codes to be created by the sender and sent to the receiver before teleportation begins. However, the standard QITP approach has the drawback of rapidly increasing the number of iterations as the amount of the text increases.

The sender will send the prefix codes to the receiver via the classical channel in order to conduct this experiment, then switch to a quantum channel in order to send the actual encoded data (using Huffman/Prefix codes). Since encoded data is transmitted over a quantum channel in which all quantum states are in superposition, even if the third party eavesdrops on the classical channel to obtain Huffman Codes/Prefix codes, the data remains safe. Therefore, any attempt to measure it will collapse the quantum state. Eavesdroppers can have the Huffman codes, but without the encoded data, which is sent over a quantum channel (Fig. 1), they are useless .

QITP with Huffman offers the advantage of increased security, although the number of iterations increases when compared to Standard QITP and even as the input file size increases. Huffman codes/Prefix codes increase data security since they make decrypting data more challenging for third party. It can only be decoded and encoded by the sender and receiver due to its unique prefix codes.

The receiver will perform some quantum operations (X and Z gates) based on classical information upon receiving quantum states from the sender (Fig. 1). The binary data is converted using Huffman/Prefix codes which are communicated over classical channels at the receiver (Bob's) end.

Prefix codes do not need to be sent over and over if the sender uses the same quantum state of the file teleported through the quantum channel but simply increases or decreases the number of qubits used, because, as shown in Table I and Table II, the prefix codes will remain the same regardless of the qubits used. It is possible to increase or decrease the number of qubits for teleportation in Standard QITP and QITP with Huffman Coding. Either Standard QITP or QITP with Huffman Coding (Standard QATP or QATP with Huffman Coding) can have more or fewer qubits. The Standard QITP and standard QATP protocol has a few constraints, however.

By adding more special characters for removing ambiguity to the text file for QITP with Huffman coding, the number of iterations would increase significantly compared to QITP without Huffman coding.

The proposed QATP with Huffman Coding is guaranteed to be more efficient than the Standard QATP (without Huffman Coding) because it reduces the number of binary sub-strings. Although the time will be longer when the number of qubits is reduced, it is still less than the time spent by the original text file in the Standard QATP.

IV. CONCLUSION AND FUTURE WORKS

For secure image transfer and secure audio transfer, two quantum image teleportation protocols (QITPs) and two quantum audio teleportation protocols (QATPs) have been proposed, using quantum teleportation (QT) and Huffman coding. The proposed QITPs (Standard QITP and QITP with Huffman Coding) and QATPs (Standard QATP and QATP with Huffman Coding) are explained in a detailed manner. IBM Quantum Experience (IBM QX) and IBM Quantum Assembly Language (IBM QASM) simulators were used to successfully demonstrate quantum state transfer of both image and audio samples files using both of the proposed QITPs and QATPs.

Future works include quantum teleportation of secure video (recorded and live video) utilizing the proposed Quantum image teleportation protocols and Quantum audio teleportation protocols suggested in this work. It is possible to combine

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quantum teleportation techniques with more traditional encryption and decryption techniques to further enhance data security and reduce the number of iterations.

V. Acknowledgements

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