Quantum Image Processing

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Introduction

- **Quantum Image Processing (QIP) is an exciting new development in which one stores classical images as quantum states and manipulates them by applying quantum gates.**

- **Compared to classical image processing QIP can store images way more efficiently (log2(n) qubits for n bits) and it can also exploit quantum parallelism.**

- **This has led to a few promising image processing algorithms such as quantum edge detection [1], quantum filtering [2] and quantum watermarking [3].**

- **In our Qiskit Community Summer Jam Project we looked at implementing QIP algorithms with Qiskit and running them on the Quantum Simulators provided by IBM. In particular we managed to watermark a quantum image with a new modified version of the algorithm presented in [3] which we will now explain.**

[1] Xi-Wei Yao, et al. *PRX* (2017)
[2] Caraiman, s. and Manta, V.I. *AECE* (2013)
[3] Panchi Li, et al. *Q. Info. Proces.* (2016)

Quantum Watermarking

- **Watermarking is the process of embedding a watermark into a carrier image. This can be an important part of physical and digital images, often used to indicate authenticity or to verify ownership.**

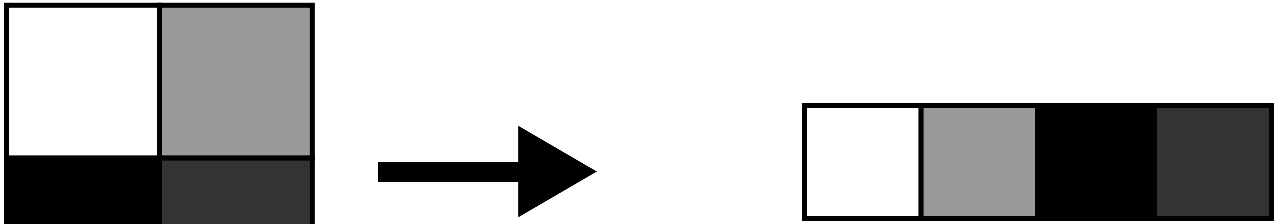
- **We will first describe the simple method we developed for including and extracting invisible watermarks in quantum images.**

- **Then we show how to scramble the watermark without affecting the image, making the watermark unrecognisable and protected from hackers. Only the true owner can recover this watermark by using its knowledge of the scrambling process.**

Watermark

Carrier image

Encoding Quantum Images

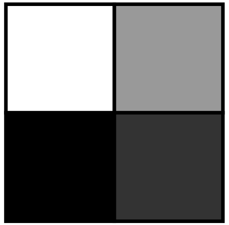


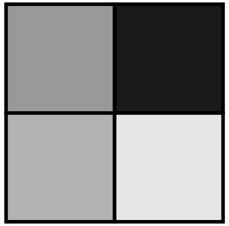
$$|\psi\rangle = \frac{1}{2}\left(\begin{matrix} |00\rangle \\ \otimes \\ |c_{00}\rangle \end{matrix} + \begin{matrix} |01\rangle \\ \otimes \\ |c_{01}\rangle \end{matrix} + \begin{matrix} |10\rangle \\ \otimes \\ |c_{10}\rangle \end{matrix} + \begin{matrix} |11\rangle \\ \otimes \\ |c_{11}\rangle \end{matrix} \right)$$

We label each classical pixel by its binary index *k* (counting from top left to bottom right) and then map it to a corresponding computational basis state $|k\rangle$ tensor product with a qubit $|c_k\rangle = cos(\theta_k/2)\,|0\rangle + sin(\theta_k/2)\,|1\rangle$ that encodes the greyscale value in the angle θ_k.

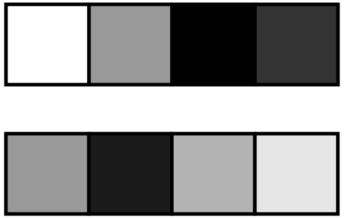
Watermarking Quantum Images

carrier





watermark



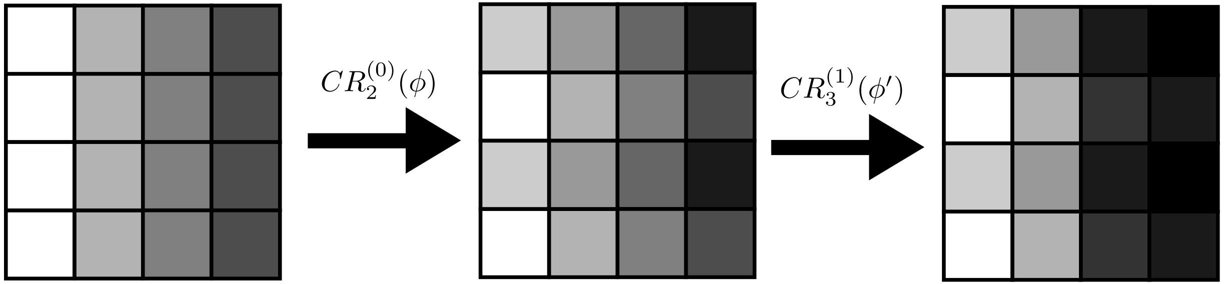
carrier

watermark

$$|\psi\rangle = \frac{1}{2}\begin{pmatrix} |00\rangle & & |01\rangle & & |10\rangle & & |11\rangle \\ \otimes & + & \otimes & + & \otimes & + & \otimes \\ |c_{00}\rangle & & |c_{01}\rangle & & |c_{10}\rangle & & |c_{11}\rangle \\ \otimes & & \otimes & & \otimes & & \otimes \\ |w_{00}\rangle & & |w_{01}\rangle & & |w_{10}\rangle & & |w_{11}\rangle \end{pmatrix}$$

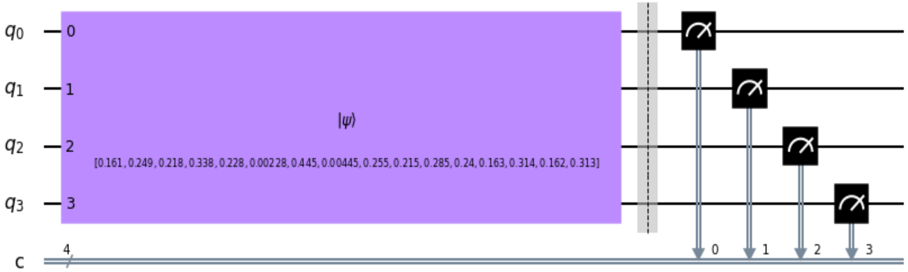
To encode the watermark we tensor product another qubit $|w_k\rangle = cos(\theta'_k/2)\,|0\rangle + sin(\theta'_k/2)\,|1\rangle$ **to each** $|k\rangle \otimes |c_k\rangle$ **with** θ'_k **the greyscale value of watermark pixel *k*.**

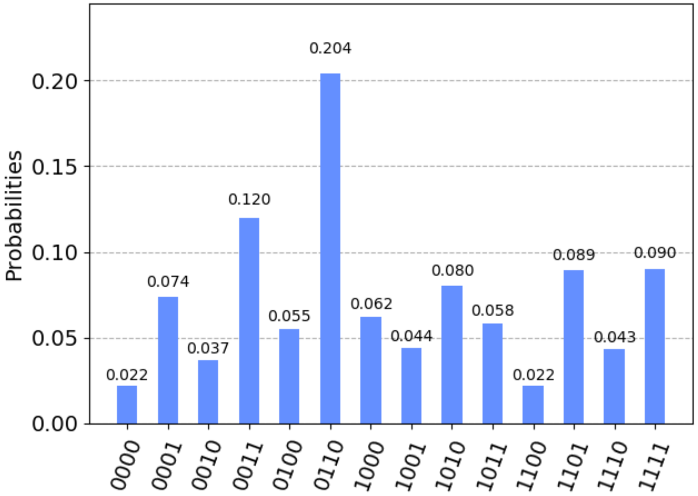
Scrambling



- **Next we scramble the watermark by applying controlled U_3 rotations $CR_n^{(i)}(\phi^i)$ with angles ϕ^i to the watermark greyscale qubit $|w_k\rangle$ controlled by the qubits *n* that encode the pixel position *k.***
- **This rotates some of the greyscale values θ'_k of the watermark image and when applied in succession on different control qubits gives a scrambling effect.**
- **Only the owner that knows the ϕ^i can recover the true watermark by applying the inverse controlled U_3 rotation gates.**

Measuring the Encoded Images

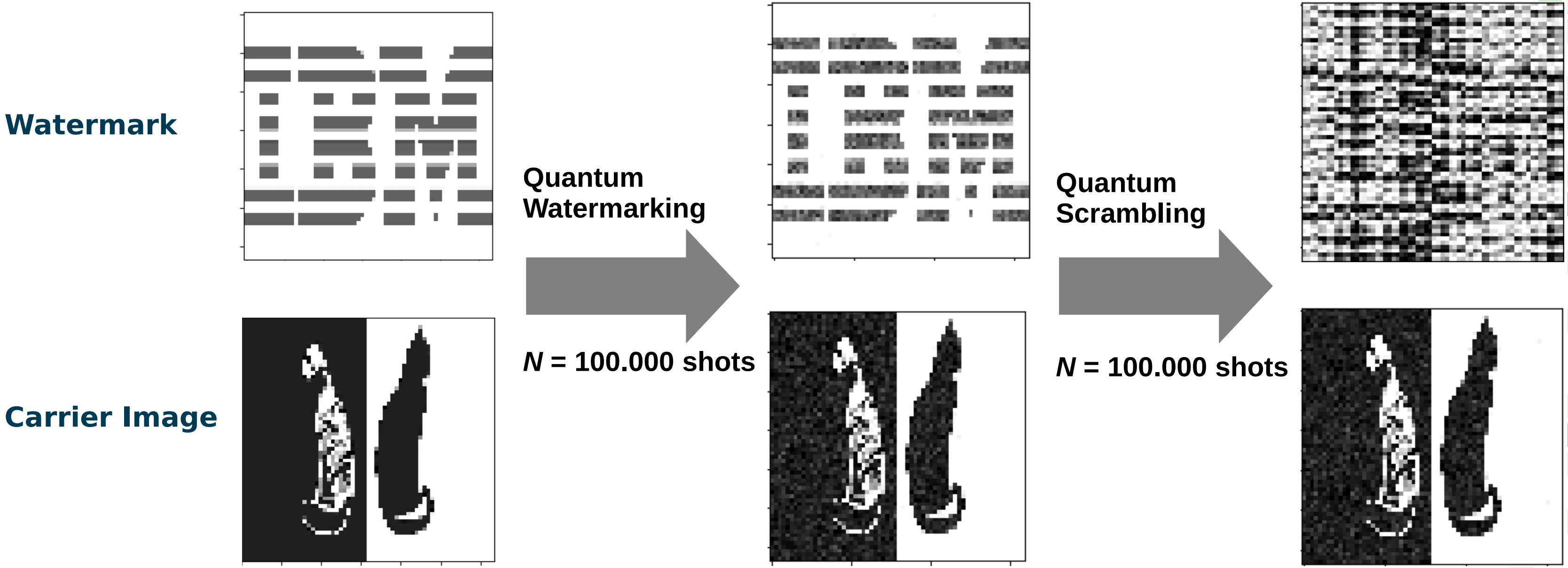




- **To retrieve the encode images we measure each qubit.**
- **The state collapses to a certain pixel *k* and either $|0\rangle$ or $|1\rangle$ for each of two the greyscale qubits $|c_k\rangle$ and $|w_k\rangle$.**
- **We denote the probabilities of these occurrences by $Pr^k(00)$, $Pr^k(01)$, $Pr^k(10)$ and $Pr^k(11)$.**
- **After many shots we can built statistics and approximate these probabilities.**
- **The probabilities can then be converted to the greyscale values of the classical images.**

Results

Here we show the results we obtained by applying our quantum watermark method for the inclusion and scrambling of an IBM logo into a Schrödinger cat picture in greyscale with a size of *64x64* pixels.

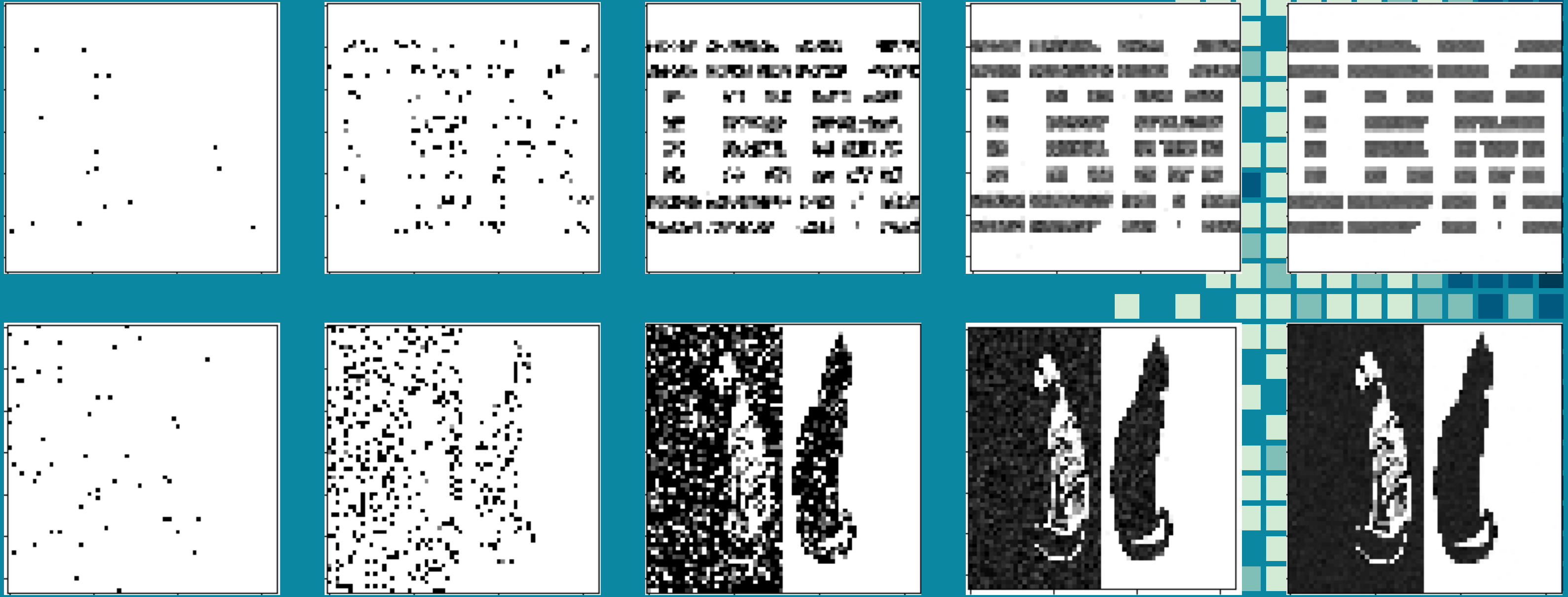


Scaling Q-Watermarking

Finally we performed also some scaling analysis to show how the watermark algorithm scales with the number of shots of the quantum circuit.

Watermark

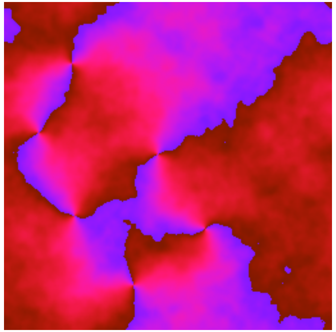
Carrier Image

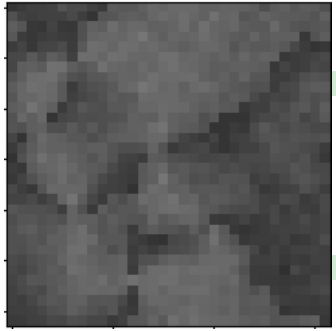


N = 100 shots | *N* = 1000 shots | *N* = 10.000 shots | *N* = 100.000 shots | *N* = 1.000.000 shots

Summary and Further Work

- **We implemented quantum encoding of classical images.**
- **Subsequently we used the quantum images to implement quantum watermarking.**
- **We then quantum scrambled the watermark to protect it from unwanted trolls.**
- **For future work we plan to extract features such as boundaries, singularities and topological information from lattice images and magnetic textures:**





THANKS!

Github picture

See our codes on Github:

../LuukCoopmans/Qiskit-Hackathon-QIP

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