Analog Quantum Computing: Numerical Calculations in a Photonic Quantum Computer

K. R. Lima, J. P. F. Neto, J. B. R. Silva, R. V. Ramos

***Resumo* — Este trabalho apresenta uma arquitetura simples de um computador quântico fotônico capaz de realizar alguns cálculos numéricos. Essa arquitetura é compacta, tem baixo consumo de energia, usa componentes ópticos comuns operando em temperatura ambiente e pode ser facilmente integrada em um chip fotônico. Simulações numéricas do algoritmo quântico proposto são realizadas.**

Palavras-Chave — Computação quântica, computador quântico fotônico, simulações numéricas.

***Abstract* — This work presents a simple photonic quantum computer architecture able to perform some numerical calculations. It is small and low power consuming; it uses common optical devices operating at room temperature and it can be easily integrated in a photonic chip. Numerical simulations of the proposed quantum algorithm are performed.**

Keywords* — *Quantum computing, photonic quantum computers, numerical calculations.

I. Analog Quantum Computing

Analog quantum information processing is a different way to take profit of quantum properties to perform communication [1] and computation [2]. It is called analog because there are not qubits nor qudits. The quantum nature of light is used to gain some advantages. The optical setup able to perform analog quantum computing is shown in Fig. 1

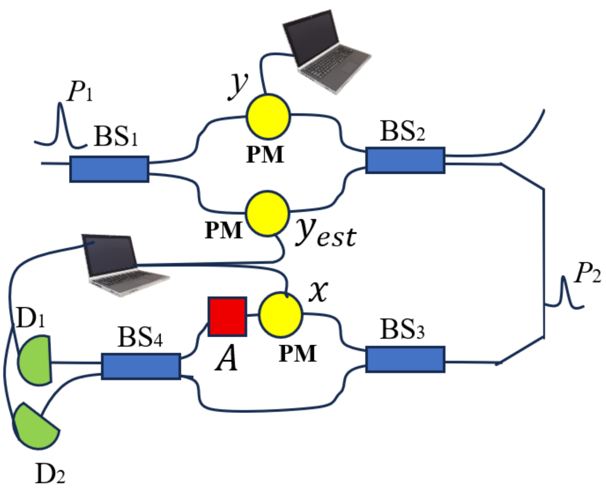

Fig. 1. Analog photonic quantum computer $BS_{1\text{-}4}$ – Balanced beam splitters, A - Optical attenuator, PM – Phase modulator. $D_{1,2}$ – Optical detectors.

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The optical setup in Fig. 1 works as follows:

1) At the first interferometer, the phase modulator at the upper arm is fed with samples of the (electrical) signal $y = f(t)$ while the phase modulator at the lower arm is fed with samples of the estimation of y, y_{est}. Each input optical pulse impinging BS_1 is a coherent state with optical power P_1. It is split in two pulses by BS_1 and, after the modulations, the two pulses will interfere at BS_2. Hence, the optical power of the pulse sent to the second interferometer is $P_2 = P_1\cos^2((y\text{-}y_{est})/2)$ (the losses are not considered).

2) At the second interferometer, the input optical pulse with power P_2 is split by BS_3 in two pulses. The pulse at the lower arm works as local oscillator while the pulse at the upper arm is phase modulated with a sample of the signal x and strongly attenuated by the optical attenuator A. The value of A is chosen such that the mean photon number of the optical pulse leaving the attenuator A is μ (a crucial parameter that should be optimized) when $y = y_{est}$.

3) The homodyne detection (the difference of the photocurrents of D_1 and D_2) measures the value of x, x_{est}. If $|x - x_{est}| < \varepsilon$, the value of x is kept otherwise it is updated according to predefined rule. For example, it can be changed by a random value.

The initial values of y_{est} and x are equal and randomly chosen. If the sample value of y_{est} is close enough to the sample value of y, the mean photon number μ will be large enough to permit a good measurement of x, keeping it to the next round. On the other hand, if the sample value of y_{est} is not close enough to the sample value of y, the mean photon number μ will not be large enough to permit a good measurement of x. In this case, the vacuum component will be relevant and there is a considerable probability that the x value will be updated. The y_{est} is updated according to: $y_{est} = f(x)$. After several rounds, y_{est} tends to y and x tends to t. One may note here that the quantum property of the light is responsible for (with a probability that depends on μ) selecting good values of x to the next round and to forbid bad values of x to be kept for the next round. Therefore, knowing only y and the function f, the proposed algorithm estimates $t = f^{-1}(y)$.

II. Numerical Simulations

Initially a simulation of the algorithm implemented by the setup shown in Fig. 1 was performed using $\mu = 4$, 1000 rounds and a new value for x was randomly chosen every time the optical pulse after the optical attenuator was a vacuum state. The input signal is $y = [\sin(t)+0.5\sin(3t)]^{1/2}$. The goal is to track $y(t)$ with $y_{est}(x)$ so, obviously, $y_{est} = f(x) = [\sin(x)+0.5\sin(3x)]^{1/2}$. Both signals y and y_{est} are shown in Fig. 2.

In the second example, the proposed quantum analog algorithm was used to find the real zeros of the polynomial z^3-2z^2+1.1875z-0.1875. Once more it was used μ = 4, 1000 rounds and a new value for x was randomly chosen every time the optical pulse after the optical attenuator was a vacuum state. The signal y was kept with the constant value zero, $y(t) = 0$, and $y_{est} = f(x) = x^3-2x^2+1.1875x-0.1875$. Figure 3 shows the best values of x and y_{est} obtained during the simulation.

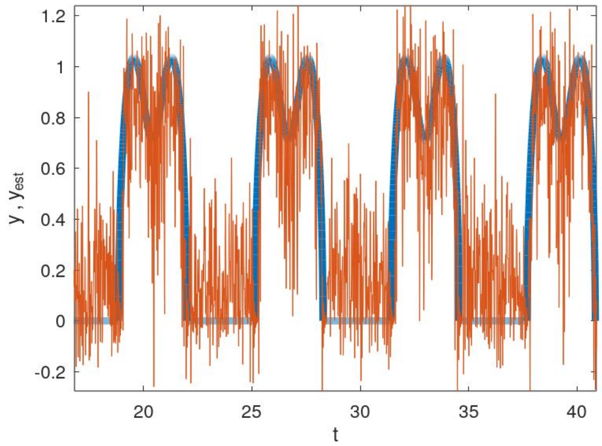

Fig. 2. $y = [\sin(t)+0.5\sin(3t)]^{1/2}$ (blue line) and y_{est} (red line) versus t.

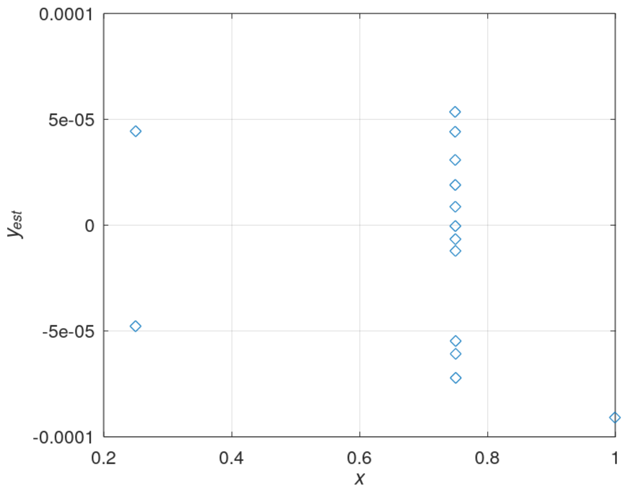

Fig. 3 – The real zeros of the polynomial z^3-2z^2+1.1875z-0.1875 (0.25, 0.75, 1). (y_{est} versus x)

At last, Fig. 4 shows the results of the numerical calculation of the solution of the problem $0.2^z+0.3^z = 1$. Once more it was used μ = 4, 1000 rounds and a new value for x was randomly chosen every time the optical pulse after the optical attenuator was a vacuum state. The signal y was kept with the constant value one, $y(t) = 1$, and $y_{est} = f(x) = 0.2^x+0.3^x$. The best result found was ~ 0.49626 while the correct value is ~ 0.496337.

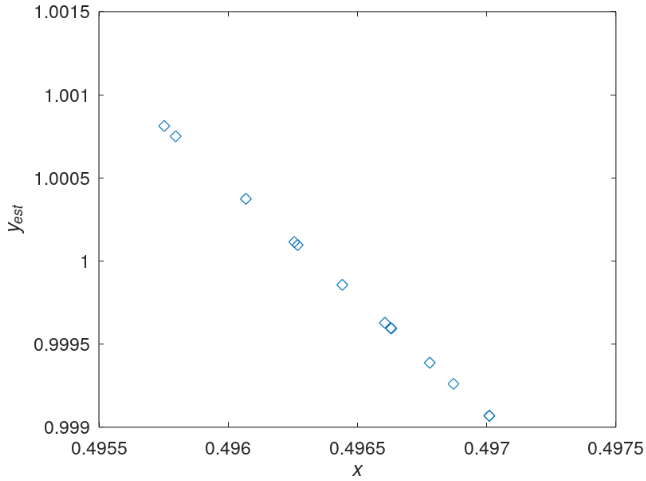

Fig. 4. Best approximated solutions of the problem $0.2^z + 0.3^z = 1$ (y_{est} versus x).

III. Conclusions

The photonic quantum computer here presented is small, low power consuming, it uses common optical devices operating at room temperature and it can be integrated in a photonic chip. The strategy chosen to update the x value is crucial to have a good answer. Just replacing it for a new random value is the simplest but the results are not so accurate, as shown in Fig. 2. On the other hand, the accuracy of the result obtained also depends critically of a good choice for the mean photon number of the optical pulse after attenuator A. If it is too low, good values of x will (probably) be changed and if it is too high bad values of x will (probably) not be changed. At last, classical signal processing algorithms can be used to improve the accuracy of the results.

Acknowledgments

This work was partially supported by the Brazilian agencies CNPq (304188/2025-5) and CAPES (001).

References

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