Some potential applications of feed-forward control

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1 Generic interferometer - VQA

In this section, we present some applications of feed-forward circuits. Feed-forward requires some time delay components (eventually with high refraction coefficient) since changing a generic interferometer parameters takes roughly 10 ms.

For the purpose of illustration, we use the VQA circuit of [1]. We propose the feed-forward version in fig. 1.

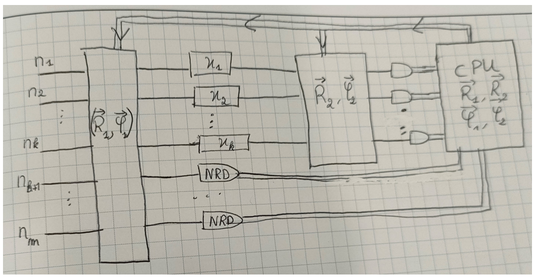

Figure 1: Photonic circuit for the first application

Here we work on a k-dimensional classification problem. We use a classical minimization algorithm in order to train the two generic interferometers. Nevertheless, we use $\mathrm{m}-\mathrm{k}$ additional modes. After the first m-mode generic interferometer, the first k modes enter into phase shifers whose phases are the coordinates of the data point. The last $\mathrm{m}-\mathrm{k}$ are detected through *number resolving detectors*.

The detection results are sent to the classical `CPU` that uses them in order to fine-tune the values of the k-mode generic interferometer. At the end, the k-remaining modes are detected (the detection can be in any fashion).

1.1 Application: faster computation

Since probability distributions can be approximated through experimental sampling, we need to be able to minimize the time required for each run. One way of doing so is by minimizing the time required for changing the circuit parameters. This feature is also consequential since longer delays mean less quantum coherence.

Here, we can use our scheme if we use a *low number of photons.* We propose the algorithm 1.

Algorithm 1 First application algorithm

$N \leftarrow \sum_{i=1}^{m} n_i - \sum_{i=k+1}^{m} n'_i$ ▷ The number of photons remaining in the circuit
if $N = 2$ **then**
  Set the $\vec{R_2}$ and $\vec{\phi_2}$ parameters
else if $N = 1$ **then**
  Set the $\vec{R_2}$ parameters ▷ Only the beam splitters reflection plays a role in the remaining photon behavior
else$N$ is odd
  Do nothing ▷ There is no photon passing through the second generic interferometer
end if

As one can see, this algorithm exploits our knowledge of the relevant second interferometer parameters. It reduces therefore the time required for setting the aforementioned parameters, hence reducing computation time.

2 Parity testing with space qubits

In this section, we base ourselves on the article [3]. It presents a polarization photonic circuit for parity testing. Parity testing allows for copying a state on an ancilla qubit while destroying it on the original qubit. The circuit used in [3] uses feed-forward control and post-selection.

Here, we present a space qubit equivalent, see fig. 2. As usual, the horizontal polarization is mapped into the Fock state $|1, 0 >$ and the vertical into $|0, 1 >$. The first component is a permutation (i.e. a relabeling of the modes). It simulates the effect of the first polarizing beam splitter. The second component, which is a tunable beam splitter, simulates the effect of the 45° degrees polarizing beam splitter. The two detectors (which should distinguish between zero, single and multi-photon detections) are used for post-selection and feed-forward control of the π-phase shifter.

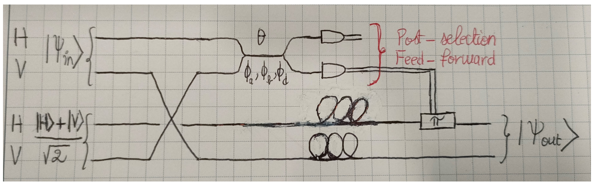

Figure 2: Boson sampling circuit for parity testing

The parameters of the tunable beam splitter should be:

$$\theta = \frac{\pi}{4}$$
$$\phi_a = 0$$
$$\phi_b = -\frac{\pi}{2}$$
$$\phi_d = -\pi$$

so as to gate a Hadamard gate. The goal of this gate is to transfer the information about the initial state from the first two modes to the other two.

Since we want to transfer the initial state into the ancilla qubit, we want to get sure that the output state contains exactly one photon. Therefore, we need to post-select in order to get rid of the cases where zero or two photons are detected. As shown in [3], the feed-forward control of the phase shifter is justified by the computation of the evolution of the post-selected states.

In order to account for the time needed for post-selection and feed-forward control, we delay the photons during the duration required for the aforementioned classical computations.

The articles [3] and [2] provide some insights on the experimental implementation of the feed-forward control.

References

[1] Beng Yee Gan, Daniel Leykam, and Dimitris G. Angelakis. "Fock State-enhanced Expressivity of Quantum Machine Learning Models". In: *EPJ Quantum Technol.* (2021), pp. 1–16. DOI: `https://doi.org/10.48550/arXiv.2107.05224`.

[2] Tiefenbacher F. et al Prevedel R. Walther P. "High-speed linear optics quantum computing using active feed-forward". In: *Nature 445, 65–69* (2007). DOI: `https://doi.org/10.1038/nature05346`.

[3] B.C. Jacobs T.B. Pittman and J.D. Franson. "Demonstration of Feed-Forward Control for Linear Optics Quantum Computation". In: *Phys. Rev. A 66, 052305* (2002). DOI: `https://doi.org/10.1103/PhysRevA.66.052305`.