A REPORT ON:

"The resurgence of the linear optics interferometer — recent

advances & applications"

BY

Si-Hui Tan and Peter P. Rohde

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It is a relatively short but comprehensive review on recent applications of linear-optical interferometers to quantum information processing and quantum engineering. These interferometers include the Mach-Zehnder interferometer and its multiport generalizations.

It is an interesting, up-to-date, and sound review having a logical and consistent structure. I have enjoyed reading this manuscript.

Thus, I could recommend the manuscript for publication in "Reviews in Physics".

I would only suggest the authors to mention some other closely-related topics (including, e.g., quantum simulations, quantum key distribution based on interferometers, or optimal quantum cloning also based on interferometers), as I list below.

I understand that the literature on quantum-information applications of quantum-optical interferometers is overwhelming, so it is a matter of personal choice to cite some of these articles and ignore the vast majority. Anyway, this review cites

only 126 references. Quite often regular articles (published in, e.g., PRA) have a similar number of references. Thus, I would also suggest to cite more relevant papers.

Here are my detailed comments:

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(1) It is written in the Introduction that:

> "In 2001, Knill, Laflamme and Milburn (KLM) showed that efficient

> quantum computing is possible using only linear optical

> components, that is single photons, beamsplitters, phase shifters

> and photon counting [3]"

Note that "efficient quantum computing ... using only linear optical components" has been independently introduced by:

> M. Koashi, T. Yamamoto, and N. Imoto,

> Probabilistic manipulation of entangled photons,

> Physical Review A 63, 030301(R) (2001).

This reference was published on 12 February 2001, while [3] was published on 4 January 2001, so almost simultaneously.

(2) Surprisingly, the field of quantum simulation in not mentioned in this review at all. However, boson sampling has been often discussed in relation to classical and quantum simulations.

For example,

> Diego G. Olivares, Borja Peropadre, Alán Aspuru-Guzik, Juan José García-Ripoll

> Quantum Simulation with a Boson Sampling Circuit

> Phys. Rev. A 94, 022319 (2016)

Also efficient classical simulation of linear-quantum optics was discussed in

> S. Rahimi-Keshari, T. C. Ralph, C. M. Caves

> Sufficient Conditions for Efficient Classical Simulation of Quantum Optics

> Phys. Rev. X 6, 021039 (2016)

Reviews on quantum simulation include:

> I. Buluta, F. Nori,

> Quantum Simulators,

> Science 326, 108-111 (2009).

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> I. Georgescu, S. Ashhab, F. Nori,

> Quantum Simulation,

> Rev. Mod. Phys. 86, 153 (2014).

(3) Quantum key distribution (QKD) is mentioned \*only\* in the Introduction as follows:

> "Photons make fantastic ‘flying’ qubits, and are readily used for

> quantum communication [1] and quantum key distribution [2]"

QKD for secure quantum communication is one of a very few commercial applications of quantum optics. So, this topic deserves to be shortly discussed in this review. This might be combined with quantum computation in Sec. 9.1.

For example,

(3.1) the B92 protocol is a standard example of quantum key distribution, which can be based on Mach-Zehnder interferometer, as introduced and described by:

> C. H. Bennett,

> Quantum cryptography using any two nonorthogonal states,

> Phys. Rev. Lett. 68, 3121 (1992)

The B92 protocol has been experimentally implemented as reported, e.g.,

> R. J. Hughes, G. L. Morgan, C. G. Peterson,

> Practical quantum key distribution over a 48-km optical fiber network,

> Journal of Modern Optics 47 (2000).

(3.2) A recent sound proposal of a QKD protocol by:

> T. Sasaki, Y. Yamamoto, M. Koashi

> Practical quantum key distribution protocol without monitoring signal disturbance

> Nature 509, 475–478 (2014)

also uses the Mach-Zehnder interferometer (on Bob's site.)

Note that this QKD has also been experimentally implemented:

> H. Takesue, T. Sasaki, K. Tamaki, and M. Koashi

> Experimental quantum key distribution without monitoring signal disturbance

> Nature Photonics 9, 827–831 (2015)

(3.3) Moreover, entanglement-based quantum key distribution based

on the Franson interferometer:

> J.D. Franson,

> Bell Inequality for Position and Time,

> Phys. Rev. Lett. 62, 2205 (1989).

has been attracting some interest, see, e.g.:

> T. Brougham et al.

> Security of high-dimensional quantum key distribution protocols using Franson interferometers

> J. Phys. B: At. Mol. Opt. Phys. 46 (2013) 104010.

> I. Ali-Khan, C. J. Broadbent, and J. C. Howell,

> Large-Alphabet Quantum Key Distribution Using Energy-Time Entangled Bipartite States,

> PRL 98, 060503 (2007)

(4) Quantum engineering based on the multi-port Mach-Zehnder interferometer of Reck et al. [31] has also attracted some interest.

For example, quantum teleportation, state truncation (linear photon-blockade), and hole burning in Fock space using this interferometer were discussed by:

> A. Miranowicz et al.,

> Selective truncations of an optical state using projection synthesis,

> J. Opt. Soc. Am. B 24, 379-383 (2007)

(5) Optimal quantum-optical cloning implementations are also based on (lossy) Mach-Zehnder interferometers (referred to as a beam divider assembly). These cloners were applied, e.g., for the eavesdropping of realistic QKD systems and the forgery of quantum money by, e.g.:

> K. Bartkiewicz et al.,

> Experimental quantum forgery of quantum optical money,

> npj Quantum Information 7 (3) 1 (2017).

> H. Fan et al.,

> Quantum Cloning Machines and the Applications,

> Phys. Rep. 544, 241 (2014).

> K. Bartkiewicz et al.,

> Experimental eavesdropping based on optimal quantum cloning,

> Phys. Rev. Lett. 110, 173601 (2013).

(6) LIGO experiment based on Michelson interferometer can be mentioned in one sentence in the Introduction:

> B.P. Abbott et al.,

> Observation of Gravitational Waves from a Binary Black Hole Merger,

> Phys. Rev. Lett. 116, 061102 (2016)

(7) There are various linear-optical implementations of two-qubit

gates. A list of 30 such implementations of CS/CNOT gates is presented in:

> M. Bartkowiak and A. Miranowicz,

> Linear-optical implementations of the iSWAP and controlled NOT gates based on conventional detectors,

> J. Opt. Soc. Am. B 27, 2369-2377 (2010)

(8) A note can be added to the caption of Fig. 1, that the setup describes a generalized multi-port Mach-Zehnder interferometer.

(9) In order to describe more realistic (imperfect) photon-number detectors, it can be mentioned in Sec. 8 that positive-operator-valued measures (POVMs) should be used to describe the effects of detector finite efficiency, finite-number resolution, and dark counts. Such POVMs are discussed in, e.g.:

> S. M. Barnett, L. S. Phillips, and D. T. Pegg,

> Imperfect photodetection as projection onto mixed states,

> Opt. Commun. 158, 45 (1998).

>

> S. Ozdemir et al.,

> Quantum-scissors device for optical state truncation: A proposal for practical realization,

> Phys. Rev. A 64, 063818 (2001).

(10) The following relevant book can be cited:

> P. Kok and B. W. Lovett,

> Introduction to Optical Quantum Information Processing,

> Cambridge Univ. Press, 2010

Minor comments:

(11) There are typos in the titles of a few references, e.g.,

[13,24,32,79,107,112]

(12) Please correct the spelling of Zehnder in the phrase

"Mach-\*Zedner\* interferometer" in two places.

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