Buraczewski, A.; **Stobińska, M.**

Numerical model for macroscopic quantum superpositions based on phase-covariant quantum cloning. (English) Zbl 1296.81005

Comput. Phys. Commun. 183, No. 10, 2245-2253 (2012).

Summary: Macroscopically populated quantum superpositions pose a question to what extent the macroscopic world obeys quantum mechanical laws. Recently, such superpositions for light, generated by an optimal quantum cloner, have been demonstrated. They are of fundamental and technological interest. We present numerical methods useful for modeling of these states. Their properties are governed by a Gaussian hypergeometric function, which cannot be reduced to either elementary or easily tractable functions. We discuss the method of efficient computation of this function for half-integer parameters and a moderate value of its argument. We show how to dynamically estimate a cutoff for infinite sums involving this function performed over its parameters. Our algorithm exceeds double precision and is parallelizable. Depending on the experimental parameters it chooses one of the several ways of summation to achieve the best efficiency. The methods presented here can be adjusted for analysis of similar experimental schemes.

Program summary

Program title: MQSVIS

Catalogue identifier: AEMR_ v1_ 0

Program summary URL: http://cpc.cs.qub.ac.uk/summaries/AEMR_v1_0.html

Program obtainable from: CPC Program Library, Queen's University, Belfast, N. Ireland

Licensing provisions: Standard CPC licence, http://cpc.cs.qub.ac.uk/licence/licence.html

No. of lines in distributed program, including test data, etc.: 1643

No. of bytes in distributed program, including test data, etc.: 13212

Distribution format: tar.gz

Programming language: C with OpenMP extensions (main numerical program), Python (helper scripts).

Computer: Modern PC (tested on AMD and Intel processors), HP BL2x220.

Operating system: Unix/Linux.

Has the code been vectorized or parallelized?: Yes (OpenMP).

RAM: 200 MB for single run for 1000×1000 tile

Classification: 4.15, 18.

External routines: OpenMP

Nature of problem:

Recently, macroscopically populated quantum superpositions for light, generated by an optimal quantum cloner, have been demonstrated. They are of fundamental and technological interest. Their properties are governed by Gaussian hypergeometric function ${}_2F_1$ of half-integer parameters, which cannot be reduced to either elementary or easily tractable functions. Computation of the photon number distribution, visibility, and mean number of photons, necessary for characterization of these states, requires evaluation of infinite sums involving this function performed over its parameters.

Solution method:

The MQSVIS program suite computes various quantum indicators, such as photon number distribution, visibility, mean number of photons, and variance, for macroscopic quantum superpositions of light. It takes losses (modeled with a beam splitter) and imperfect photodetection (modeled with a Weierstrass transform applied to the photon number distribution) into account. Cutoffs of the infinite hypergeometric sums are estimated dynamically, and precision is enhanced with the computation of expressions in logarithmic form. Depending on the experimental parameters, the program chooses one of several ways of summation to achieve the best efficiency. The program is parallelized using OpenMP standard, which

ensures the best utilization of multicore processors, and splits the work into tiles computed with different nodes of a computer cluster. This allows computation of the required indicators for realistic values of the parameters.

Running time:

1–2 h for a 1000×1000 tile, depending on the values of the parameters.

MSC:

81-04 Software, source code, etc. for problems pertaining to quantum theory
81P40 Quantum coherence, entanglement, quantum correlations
81P50 Quantum state estimation, approximate cloning

Keywords:

macroscopic quantum superpositions; macroscopic entanglement; optimal quantum cloning; Gaussian hypergeometric function; quantum optics

Software:

MQSVIS; mpmath; gmp; CLN

Full Text: DOI arXiv

References:

[1] Schrödinger, E., Naturwiss., 23, 807, (1935)
[2] Friedman, J.R., Nature, 406, 43, (2000), and references therein
[3] I. Usmani, Ch. Clausen, F. Bussieres, N. Sangouard, M. Afzelius, N. Gisin, arXiv:1109.0440.
[4] Lee, K.C., Science, 334, 1253, (2011)
[5] Nagali, E.; De Angelis, T.; Sciarrino, F.; De Martini, F., Phys. rev. A, 76, 042126, (2007)
[6] De Martini, F.; Sciarrino, F.; Vitelli, Ch., Phys. rev. lett., 100, 253601, (2008)
[7] Wootters, W.K.; Zurek, W.H., Nature, 299, 802, (1982)
[8] Scarani, V.; Iblisdir, S.; Gisin, N., Rev. math. phys., 77, 1225, (2005)
[9] Iskhakov, T.; Chekhova, M.V.; Leuchs, G., Phys. rev. lett., 102, 183602, (2009)
[10] Zurek, W.H., Rev. math. phys., 75, 715, (2003)
[11] Vitelli, C.; Spagnolo, N.; Toffoli, L.; Sciarrino, F.; De Martini, F., Phys. rev. A, 81, 032123, (2010)
[12] Jedrkiewicz, O.; Blanchet, J.-L.; Gatti, A.; Brambilla, E.; Di Trapani, P., Opt. express, 19, 12903, (2011)
[13] Bartlett, S.D.; Sanders, B.C.; Braunstein, S.L.; Nemoto, K., Phys. rev. lett., 88, 097904, (2002)
[14] Stobińska, M.; Sekatski, P.; Buraczewski, A.; Gisin, N.; Leuchs, G., Phys. rev. A, 84, 034104, (2011)
[15] Sekatski, P.; Brunner, N.; Branciard, C.; Gisin, N.; Simon, C., Phys. rev. lett., 103, 113601, (2009)
[16] M. Stobińska, P. Horodecki, A. Buraczewski, R.W. Chhajlany, R. Horodecki, G. Leuchs, arXiv:0909.1545.
[17] M. Stobińska, F. Töppel, P. Sekatski, A. Buraczewski, M. Żukowski, M.V. Chekhova, G. Leuchs, N. Gisin, arXiv:1108.4906.
[18] Petkovšek, M.; Wilf, H.S.; Zeilberger, D.; Wilf, H., A=b, (1997), Peters/CRC Press
[19] Abramowitz, M.; Stegun, I.A., ()
[20] Michel, N.; Stoitsov, M.V., Comput. phys. commun., 178, 535, (2008)
[21] Lopez, J.L.; Pagola, P.J., J. comput. appl. math., 233, 1570, (2010)
[22] Temme, N.M., J. comput. appl. math., 153, 441, (2003)
[23] Miller, A.R., J. comput. appl. math., 157, 507, (2003)
[24] Gautschi, W., J. comput. appl. math., 139, 173, (2002)
[25] Luke, Y.L., J. approx. th., 5, 41, (1972)
[26] 754-2008 IEEE Standard for Floating-Point Arithmetic, http://dx.doi.org/10.1109/IEEESTD.2008.4610935.
[27] The GNU multiple precision arithmetic library, http://gmplib.org/.
[28] Fousse, L.; Hanrot, G.; Lefèvre, V.; Pélissier, P.; Zimmermann, P., Toms, 33, 13, (2007), http://www.mpfr.org/
[29] CLN—class library for numbers, http://www.ginac.de/CLN/.
[30] mpmath—Python library for arbitrary-precision floating-point arithmetic, http://code.google.com/p/mpmath/.
[31] Aitken, A., Proc. roy. soc. Edinburgh, 46, 289, (1926)

[32] Press, W.H.; Teukolsky, S.A.; Vetterling, W.T.; Flannery, B.P., Numerical recipes in C, (1997), Cambridge Univ. Press

[33] Shanks, D., J. math. phys., 34, 1, (1955)

[34] Richardson, L.F., Philos. trans. R. soc. lond. A math. phys. eng. sci., 210, 307, (1911)

[35] Brezinski, C.; Redivo Zaglia, M., Extrapolation methods, Theory and practice, (1991), North-Holland · Zbl 0814.65001

[36] P. Fackler, Inverse digamma (psi) function, http://www4.ncsu.edu/~pfackler/. · Zbl 1359.47038

[37] This approach has been discussed with R.W. Chhajlany.