Entangled Microscopy

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The major factor in light microscopy limiting resolution in practice is not so much the wavelength of light and the resolving power of microscope optics, but the scattering of light by the specimen. This extraneous scattered light interferes with the light used to image the specimen, effectively reducing the contrast of the imaging light and causing other annoying problems. There have been several inventions dedicated to solving this problem: various forms of interference-based microscopies, confocal microscopy, and most recently, multi-photon confocal microscopy.

While these microscopies all have achieved some measure of success, none have addressed one of the fundamental difficulties: the photons (or electrons) that actually form the image must pass on through the rest of specimen and the microscope's optics to be detected and so form the image. This also results in scattering and other losses that degrade the light actually used for imaging, reduces the contrast within the signal and so lowers the maximum achievable resolution.

We at the Piltdown Research Institute have been struggling to resolve this problem, and have recently hit upon what promises to be the perfect solution to this problem. Indeed, our solution should improve not just light microscopy but also electron microscopy, and even lead to true Telepresence Microscopy – microscopy at a distance without the Internet.

The first hint techniques needed to accomplish this came when we remembered that light is after all photons and so quantum mechanical, and that microscopy is in essence applied quantum mechanics.* This was triggered by recent experiments on Bell's Theorem and quantum teleportation[1-4].

Briefly, Bell's Theorem is complicated. In quantum mechanics, if a photon is split to produce two entangled (because of their common origin) photons of lesser energy and then sent on their separate ways, the energy or momentum (arrival time) of one photon can be detected by measuring its twin somewhere else. The measurement of the first photon instantaneously determines the state of the second photon, wherever it is. Einstein called this "spooky action at a distance", and tried to disprove it. Unfortunately, this behavior has stood the test of time, and is effective even over kilometers of distance. Quantum teleportation is the same sort of annoying event, only it involves "teleporting" a quantum state (such as polarization) from one photon to its twin. According to quantum mechanics, if two photons are entangled by shining a single photon into a crystal that splits the one photon into two oppositely polarized photons, the polarization of the photons is unknowable until one is measured . Measuring the polarization of one of the photons instantaneously determines the polarization of its twin, even though they are separated by a great distance.

This was the "Ah-ha!" moment. Why not use the specimen as the detector? This would solve the all those vexing problems that scatter and otherwise degrade the light (or electrons) used to construct an image. First, make a pair of entangled photons, then separate them and send one photon to the specimen, and the other to a detector. The detector can be film or a CCD chip, a polarization detector, or whatever is attracting grant funding at the moment, and has to be the same distance from the splitting crystal as the specimen is from the crystal. The photons are scanned over the specimen (1st photon) and detector (2nd photon). As the first photon of the entangled pair is detected by the specimen, the second photon of the pair immediately assumes its proper quantum state, which is measured by the detector. Viola! An image is formed without the imaging photon ever encountering the specimen.

Since the first photon only encounters the first part of the specimen that detected it, it is unaffected by scattering or other signal-degrading events that occur afterwards. This is unlike standard microscopies, in which imaging photons must be detected (affected in some manner) by the specimen, and then pass on through the specimen, with losses due to scattering, absorption, and other events that do not contribute to image formation. Further the second photon of the pair is also undisturbed, since it has already passed through any lenses or other equipment prior to its quantum state being determined by the specimen's detection of the first photon. Therefore there are no problems with being out-of-focus, or signal losses from diffraction, absorption, *etc.* All the information from any arbitrarily defined image surface can be obtained with no noise. Result: the cleanest possible signal and maximum contrast and resolution.

Naturally this also led us to realize that true Telepresence Microscopy was possible this way. Just feed the first photon of the pair into a great long coil of fiber-optic cable before it got to the specimen, and send the second photon through a standard telephone company fiber-optic cable. Measure the distance the second photon has to travel to reach the detector in the distant lab, and adjust the distance the first photon travels in its coil in the microscope's lab. The first photon is detected by the specimen, and its entangled twin is detected in the distant lab, forming the image. This will require very high grade cables and very sensitive equipment, since the photons cannot be amplified without loss of their identity and entanglement.

This left only the most important part of any new discovery – deciding on the name of the new microscopy. We at first wanted to use Einstein's "Spooky Action at a Distance" phrase for entanglement, but soon realized the less than salubrious effect the acronym would have on granting agencies. Who would fund SAD microscopy? So we have settled on Entangled Microscopy, in spite of the obvious pun with web-weaving.

References:.

1) Bouwmeester and Zellinger. Nature 388:827, 1997.
2) Bouwmeester *et al.* Nature 390:575,1997.
3) Braunstein and Kimble. Nature 394:840,1998.
4) Bouwmeester *et al.* Nature 394:841, 1998.

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This realization came when the administration was once again pressuring the P.R.I. to save money by closing the Central Microscopy Facility. Simply changing the facility's name to the Applied Quantum Mechanics laboratory once again gave us an exciting and impressive name. This change not only heightened our status with the University administration, but increased our grant applications success rate. ■

This research was funded in part by the Jongleurs' Guild for Japery and Jests.

January 1, 2000

Dear Valued Employee

Re: Vacation Pay

Our records indicate that you have not used any vacation time over the past 100 years.

As I'm sure you are aware, employees are granted 3 weeks of paid leave per year or pay in lieu of time off. One additional week is granted for every 5 years of service. Please either take 9,400 days off work or notify our office and your next pay will reflect payment of $8,277,432.22 which will include all pay and interest for the past 1,200 months.

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May 17/21 '99: Scanning Electron Microscopy – Session 1
May 18-21 '99: Image Analysis
May 24-28 '99: Scanning Electron Microscopy – Session II
May 25-28 '99: X-ray Microanalysis
(Univ. of Maryland) College Park, MD. Tim Maugel: (301)405-6898

Marine Biological Laboratory Courses, Woods Hole, MA
May 6/14 '99: Analytical & Quantitative Light Microscopy
May 18/25 '99: Microinjection Techniques in Cell Biology
Oct 6/14 '99: Optical Microscopy & Imaging in the Biomedical Sciences
Carol Hamel: (508)289-7401, eMail: admissions@mbl.edu

McCrone Research Institute (Selected) Microscopy Courses, Chicago, IL
June 21/25 '99: Electronic Image Acquisition, Processing & Analysis
Nancy Daerr: (312)842-7100, Fax: (312)842-1078, ndaerr@mcri.org

✓ April 18/23 '99: **Cryo Techniques and Immunogold Workshop** (Univ. of Georgia & Leica Microsystems). Atlanta, GA. Ms. Hong Yi: (404)727-8692

✓ May 3/7 '99: **EMAS 99 Workshop on Dev and Applic in Microbeam Analysis.** Konstanz, Germany, email: vantdack@uia.ua.ac.bc

✓ May 10/14 '99: **Cross-Sectional Transmission Electron Microscopy, Preparation and Characterization of Thin Films.** (Colorado School of Mines) Golden, CO. (303)273-3321, Fax: (303)273-3314, www.mines.edu/Outreach/Cont_Ed

✓ May 20/22 & 24/26 '99: **Workshop on Quantitative Image Analysis** (North Carolina State University), Raleigh, NC. Cindy Allen: (919)515-8171, email: cindy_allen@ncsu.edu

✓ May 26/28 '99: **MSC/SMC Conference – Eye on Imaging.** (Microscopical Society of Canada) Guelph, ON, Canada. www.uoguelph.ca/botany/rootlab/msc99/htm

✓ May 30/June 1 '99: **Scanning Probe Microscopy, Cantilever Sensors and Nanostructures** (Seattle '99 SPM Conference). Seattle, WA. http://polymer.physics.bristol.ac.uk/spm

✓ June 7/11 '99: **Polymer Microscopy Short Course** (University of Michigan) Ann Arbor, MI, http://cpd.engin.umich.edu

✓ **LEHIGH MICROSCOPY SCHOOL,** Bethlehem, PA
June 14/18 '99: SEM and X-ray Microanalysis
June 13 '99: Introduction to SEM and EDS
June 21/25 '99: Advanced Scanning Electron Microscopy
June 21/25 '99: Quantitative X-ray Microanalysis
June 21/24 '99: Analytical Electron Microscopy
June 22/25 '99: Atomic Force Microscopy
June 21/24 '99: Microdiffraction
Info: Ms Sharon Coe: (610)758-5133, email: slc6@lehigh.edu
http://www.lehigh.edu/~inmatsci/shortcourse/Microacourses.html

✓ June 16/27 '99: **3D Microscopy of Living Cells** & June 29/July1 '99: **3D Image Processing Workshop** (Univ of British Columbia) Vancouver, BC, Canada. Prof. James Pawley: (608)263-3147, jbpawley@facstaff.wisc.edu

✓ June 21/25 '99: **15th Annual Short Course on Molecular Microspectroscopy** (Miami Universtiy) Oxford, OH (513)529-2874, fax: (513)529-7284, email: http://www.muohio.edu/~sommeraj

✓ June 21/25 '99: **Fourth Annual Fundametals and Applications of Light Microscopy.** (McCann Imaging/Wellsey College) Wellsey MA. Mary McCann: (617)484-7865, Fax: (617)484-2490, www.microscopyed.com

✓ June 25/July 1 '99: **INTER/MICRO '99** (McCrone Research Institute), Chicago, IL. Nancy Daerr: (312)842-7105

✓ July 9/13 '99: **IUMAS 2000: The 2000 Meeting of the International Union of Microbeam Analysis Societies.** Kailua-Kona, Hawaii

✓ Aug 1/5 '99: **MICROSCOPY & MICROANALYSIS '99** (MSA) Portland, OR

✓ Aug 9/13 '99: **Summer School on Computing in Electron Microscopy** (NCEM, Lawrence Berkeley Natl Lab) Berkeley, CA, (510)486-6036, Fax: (510) 486-5888, http://ncem.lbl.gov