BIOGRAPHICAL SKETCH

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NAME: Sarah Kathryn Patch

eRA COMMONS USER NAME (credential, e.g., agency login): patchs

POSITION TITLE: Associate Professor

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE *(if applicable)*	Completion Date MM/YYYY	FIELD OF STUDY
Stanford University	B.S.	06/1989	Mathematics and Computational Sciences
New York University		05/1990	Applied Mathematics
University of California at Berkeley	Ph.D.	05/1994	Applied Mathematics
Institute of Mathematics & its Applications	Postdoc	08/1995	Applied Mathematics
University of Muenster, Germany	Postdoc	01/1996	Applied Mathematics
Stanford University	Postdoc	06/1997	Applied Mathematics

A. Personal Statement

The goal of this research is technology development, specifically acoustic hardware to enable online range verification during ion therapy. Two approaches will be pursued: thermoacoustics and contrast enhanced ultrasound. We will outfit standard ultrasound imaging arrays with 4-6 receivers that are sensitive to low frequency thermoacoustic emissions from clinical proton therapy systems. We will also use single elements to determine whether high-energy proton-microbubble collisions cause cavitation. To avoid siting costly electronics inside the harsh environment of a proton therapy vault we will investigate feasibility of using wireless ultrasound imaging systems. We will also investigate optical detection of thermoacoustic emissions by commercialized etalon technology that has already demonstrated radiation hardness and insensitivity to electromagnetic interference at CERN's LHC.

My early mathematical research in diffuse tomography was motivated by optical/NIR imaging, followed by cone beam reconstruction of xray CT data and motion correction for Propeller MRI during my eight years with General Electric (GE). Although my degrees are in applied mathematics, at GE I obtained a basic understanding of the physics—and painstaking engineering—required to develop clinical systems.

In the proposed work I will leverage my recent experience in quantitative thermoacoustic imaging, which also requires detection of very low frequency thermoacoustic emissions.

1. SK Patch, DEM Hoff, TB Webb, LG Sobotka, T Zhao, "Two-Stage Ionoacoustic Range Verification Leveraging Monte Carlo and Acoustic Simulations to Stably Account for Tissue Inhomogeneity and Accelerator-Specific Time Structure - a simulation study," *Medical Physics, accepted for publication.*
2. SK Patch, M Kireeff Covo, A Jackson, YM Qadadha, KS Campbell, RA Albright, P Bloemhard, AP Donoghue, CR Siero, TL Gimpel, SM Small, BF Ninemire, MB Johnson, and L Phair, "Thermoacoustic Range Verification using a Clinical Ultrasound Array Provides Perfectly co-Registered Overlay of the Bragg peak onto an Ultrasound Image," *Physics in Medicine and Biology,* **61**, pp. 5621-5638, (2016).
3. SK Patch, D Hull, WA See, GW Hanson, "Toward Quantitative Whole Organ Thermoacoustics With a Clinical Array Plus One Very Low-Frequency Channel Applied to Prostate Cancer Imaging," *IEEE Transactions on Ultrasonics, Ferroelectrics and Frequency Control*, **63**(2), pp. 245-55 (2016).

4. SK Patch, D Hull, M Thomas, SK Griep, K Jacobsohn, WA See, "Thermoacoustic contrast of prostate cancer due to heating by very high frequency irradiation," *Physics in Medicine and Biology,* **60**, pp. 689-708, (2015).
5. A Eckhart, R Balmer, W See, SK Patch, "Ex Vivo Thermoacoustic Imaging over Large Fields of View with 108 MHz Irradiation," *IEEE Transactions on Biomedical Engineering,* **58**(8), pp. 2238 - 2246, (2011).

B. Position and Honors

Positions and Employment

1997-1999 Mathematician, General Electric Corporate Research & Development
1997-1999 Adjunct (0% salary), Department of Mathematics, Rensselaer Polytechnic Institute
1999-2005 Senior Scientist, Applied Science Laboratory, GE Medical Systems
2003-present Adjunct (0% salary), Department of Medical Physics, UW-Madison
2005-present Associate Professor, Department of Physics, UW-Milwaukee
2010-present Adjunct (0% salary), Clinical and Translational Science Institute, Medical College of Wisconsin

Other Experience and Professional Memberships

- Co-editor of special issue in *Inverse Problems* devoted to photo- and thermoacoustics.
- Member, IEEE
- Sr. Member, SPIE
- Scientific committee member for Fully 3D Reconstruction in Radiology & Nuclear Medicine 2007-2013.
- Invited to participate in "Mathematical Methods in Tomography" workshops at the Mathematical Institute-Oberwolfach. Every four years starting 1994; could not attend 2010.
- Invited to present at Computational and Analytical Aspects of Image Reconstruction, ICERM-Brown University, July 2015.
- 2008-2010 NIH Industrial-Academic study section ad hoc reviewer
- 2009-2010 NIH Special Conflict study section ad hoc reviewer
- 2010 NIH BMIT study section ad hoc reviewer
- 2013 NIH Shared Instrumentation: Ultrasound and Optical Study Section reviewer
- 2013 NIH Special Emphasis Panel/Scientific Review Group
- 2013 NIH Early Independence Award reviewer
- 2004-2005 Industrial Advisory Board, Institute for Mathematics and Its Applications

Honors

- AAPM Science Council Session 2016
- National Science Foundation Postdoctoral Fellow in the Mathematical Sciences (1994-1997)
- Alexander von Humboldt Stipendiatin (1995-1996)

C. Contributions to Science

1. *Oceanographic instrumentation.* My earliest foray into research was as a summer student at Woods Hole Oceanographic Institute, where I was first introduced to the concept of very low frequency sonar measurements. My first publication, however, modeled eddy-current damping of compasses on buoys used for oceanographic measurements.
    a. S. K. Patch, E. P. Dever, R. C. Beardsley, S. J. Lentz, "Response Characteristics of the V.A.C.M. Compass and Vane Follower," *Journal of Atmospheric and Oceanic Technology*, **9,** No. 4, 459-469, (1992).

2. *Diffuse tomography*. My PhD thesis topic was motivated by diffuse optical tomography. Photon transport was modeled by an anisotropic random walk on a Cartesian lattice. My first result was to fully characterize the range of the time-independent forward problem (2a), showing that only ¾ of the measurements in a 2x2 (4-pixel) model are independent. *Analytically* solving the inverse, i.e., imaging, problem in for the 2x2 base case (2b*)* and developing a recursive method for solving larger 2D systems (2c) completed my doctoral work.
    a. S. K. Patch, "Consistency Conditions in Diffuse Tomography," *Inverse Problems*, **10**, no.1, pp. 199-212, (1994).

   b. S. K. Patch, “Recursive Recovery of a family of Markov Transition Probabilities from Boundary Value Data,” *Journal of Mathematical Physics,* **36**, no. 7, pp. 3395-3412, (1995).
   c. S. K. Patch, “Diffuse Tomography Modulo Grassmann and Laplace,” *Journal of Mathematical Physics*, **37**, no. 7, pp. 3283-3305, (1996).

3. *Volumetric computed tomography.* Inverse transport was the natural progression of my early research interest in diffuse tomography. The scatter-free inverse transport problem is essentially equivalent to x-ray CT image reconstruction. I joined GE’s Corporate R&D center in 1997 to develop cone beam CT inversion methods, and enforcing consistency conditions on measured data remained an ongoing theme in my research (3a-d). Theoretical cone beam reconstruction work utilized an ultrahyperbolic partial differential equation to extrapolate unmeasured views (3a-b) and convert a fully three-dimensional inversion problem into a family of easier two-dimensional problems (3c). Monitoring for deviations from the Helgason-Ludwig consistency conditions was developed for detecting the failure of a detector channel (3d). Seven additional x-ray CT and tomosynthesis patents, which are not listed below, were filed by GE.
   a. S. K. Patch, US Patent #6292526 “Methods and apparatus for preprocessing volumetric computed tomography data,” 9/18/2001. Issued internationally in Germany DE10053178A1, 05/10/2001. Filed internationally in Japan JP2001224584A, 08/21/2001.
   b. S. K. Patch, “Consistency Conditions upon 3D CT Data and the Wave Equation*,” Physics in Medicine & Biology,* 47 no 15, pp. 2637-2650, (2002).
   c. S. K. Patch, “Computation of Unmeasured 3rd Generation VCT Views from Measured Views,” *IEEE-Transactions in Medical Imaging,* 21 no 7, (2002).
   d. S. K. Patch, US Patent #6264365 “Background monitoring of CT data for existence and location of a bad detector,” 7/24/2001. Issued internationally in Germany DE 10052678, 04/17/2003. Filed internationally in Japan JP2001170042A, 06/26/2001.

4. MRI ad hoc contributions as GE bench scientist: spiral homodyne / high-order shim / Propeller. Business necessities and my own interest in other modalities led to specific MRI projects during my time with GE. My first foray into MRI was homodyne reconstruction of spiral data (4a). Shimming GE's ill-fated high-field open MRI systems called for a simple and robust phase unwrapping method (4b). Optimizing k-space gridding and image-space deconvolution of Propeller data was my last MRI project (4c-d).
   a. H. E. Cline, S. K. Patch, C. J. Hardy, W. A. Edelstein, US Patent application #09/312,687, MR Imaging with Partial k-space Acquisition using spiral scanning,” published 03/01/2002.
   b. S. K. Patch, T. Shubhachint, G. C. McKinnon, S. Parameswaran, J. K. Maier, US Patent #6703835 “System and method for unwrapping phase difference images,” 09/03/2004.
   c. S. K. Patch, M. R. Hartley, J. G. Pipe, US Patent #7176684, “Method and System of Determining in-plane Motion in Propeller Data,” 13/02/2007.
   d. S. K. Patch, “k-space Data Preprocessing for Artifact Reduction in MRI,” Radiological Society of North America 2005 Categorical Course in Diagnostic Radiology Physics. (Repeated 2006-7)

5. *Thermoacoustic Computed Tomography.* Reconstruction of idealized thermoacoustic data is a math problem in integral geometry. My contribution to (5a) was development of a filtered back projection inversion formula for a spherical measurement aperture in three dimensions. This paper kicked off a flurry of activity in the mathematical community, which led to theoretical solutions to issues such as limited angle measurements and distortions due to variable sound speed. Therefore, my attention turned to fundamental physical as well as hardware limitations. To ensure good homogeneity of the electric field, I work with very high frequency (VHF) electromagnetic pulses and have developed a two-port testbed that allows us to measure incident and reflected power at each port, from which field strength can be inferred (5b). My group has demonstrated that VHF energy can image over large fields of view (5c), and we also have explored effects due to polarization of the applied electric field (5d).
   a. D. Finch, S. K. Patch, Rakesh, “Determining a Function from its Mean Values over Spheres,” *SIAM J. Math. Anal.,* **35**(5), pp. 1213-1240, (2003).
   b. SK Patch, “Thermoacoustic Tomography - Consistency Conditions and the Partial Scan Problem,” *Physics in Medicine & Biology,* **49**(11), pp. 2305 – 2315, (2004).
   c. D. Fallon, L. Yan, G. W. Hanson, SK Patch, “RF Testbed for Thermoacoustic Tomography,” *Review*

of Scientific Instruments,* **80**, #064301, (2009).

d. SK Patch, D Finch, V Palamodov, US Patent #7878976, "Method and system of thermoacoustic imaging with exact inversion," 01/02/2011.
e. MA Roggenbuck, R. D. Walker, J. W. Catenacci, S. K. Patch, "Volumetric Thermoacoustic Imaging over Large Fields of View," *Ultrasonic Imaging,* **35**(1), p. 57-6, (2013). PMID: 23287507.
f. D. Li, Y.S. Jung, H.K. Kim, J. Chen, D. A. Geller, M. V. Shuba, S. A. Maksimenko, S. K. Patch, E. Forati, and George W. Hanson, "The Effect of Sample Holder Geometry on Electromagnetic Heating of Nanoparticle and NaCl Solutions at 13.56 MHz," *IEEE Transactions on Biomedical Engineering*, **59**(12), pp. 3468-3474, (2012).

Pub Med papers in MyBibliography:
http://www.ncbi.nlm.nih.gov/sites/myncbi/sarah.patch.1/bibliograpahy/48127676/public/?sort=date&direction=ascending

D. Research Support

Current Research Support

CHE-1508240 09/01/2015-08/31/2018
National Science Foundation $550,000
Advancing 3D Chemical Imaging: FTIR Spectro-microtomography, FTIR Spectro-microlaminography and Hyperspectral Data Analysis

The objective of this proposal is to (1) implement Fourier transform infrared (FTIR) spectro-micro-tomography (SmT) for samples that are extended in two dimensions, and (2) implement limited-angle reconstruction algorithms and optimize spectrochemical analysis methods to enhance spectral and image quality. Dr. Patch's role is to lead limited-angle reconstruction efforts and ensure they are optimized with respect to the system hardware and also software corrections.
Role: co-PI

Pending

HR001117S0040-Office-Wide-BAA-FP-72 11/15/2017-5/15/2017 (expected)
DARPA (Harid PI, Patch consultant) $150,000 (expected)
Broadband Low-frequency Imaging with Novel Generation
The objective of this proposal is to image remotely using extra low frequency electromagnetic signals. My role is to provide reconstruction algorithm support in an effort to overcome conventional resolution limits.
(The PI recently received positive notification, and the award is under negotiation with his grants office.)

MTA_2017004 10/15/2017-10/14/2018
Lantheus (Patch PI) in-kind contribution of Definity
Contrast-Enhanced Range Verification During Ion Therapy
The objective of this proposal is to test the hypothesis that braking protons destroy Definity microbubbles, altering contrast within the therapeutic beam but leaving contrast unaltered outside the beam.
(Lantheus approved the award in early Oct, but the legal paperwork is in limbo.)

Completed Research Support (within the last 3 years)

2013-14 Stimulus Program to Accelerate Research Clusters (SPARC)
UWM College of Health Sciences (CHS) (Mitchell) 07/01/2013-06/30/2015
Utilizing High-Frequency Ultrasound & Themoacoustic Imaging to Correlate With Biomarkers Prostate Cancer

This study examines acoustic backscatter and attenuation coefficient measures from normal prostate monolayer cell cultures (RWPE-1) and four different prostate cancer monolayer cell cultures (LNCaP, MDA PCa 2b, DU145 and PC-3). In addition to examining the monolayer cell cultures, an *in vivo* imaging protocol for subcutaneous xenograft tumors of these same four prostate cancer cell lines in an immune-deficient murine model will be employed with ultrasound and thermoacoustic tomography (TCT) imaging.
Role: co-I