Pat Pannuto

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545W Cory Hall
University of California, Berkeley
Berkeley, CA 94720

Tel: +1.248.990.4548
ppannuto@berkeley.edu
https://patpannuto.com

Research Overview and Interests

My research focuses on solving the "last inch" problem and solving the challenges that stand between the burgeoning Internet of Things and inevitable Internet of Everything. My research vision pushes towards the realization of ubiquitous and pervasive computing, aiming to understand how our interaction and utilization of technology will shift as computing becomes omnipresent and its operation and interaction shifts from conscious action to unconscious extension of perception and ability. What advancements will most change how people interact with themselves, the world, and one another, and what innovations facilitate these paradigm shifts? My interests span from low-level details—developing new technology to meet the energy and area demands of next-generation millimeter systems—to large-scale global considerations—understanding how our network and infrastructure must scale and adapt to support the trillions of impending devices.

Education

University of California, Berkeley, Berkeley, CA (2017–present)
Ph.D. Student in Electrical Engineering (degree expected summer 2019)
Advisor: Prabal Dutta

University of Michigan, Ann Arbor, MI (2012–2017)
M.Eng. in Computer Science
Advisor: Prabal Dutta

University of Michigan, Ann Arbor, MI (2007–2012)
B.S.Eng in Computer Engineering

Awards and Honors

University of Michigan Rackham Graduate School Outstanding Graduate Student Instructor (2017)

University of Michigan College of Engineering Richard & Eleanor Towner Prize for Outstanding Graduate Student Instructors (2017)

University of Michigan College of Engineering Featured Graduate Student (Fall 2014)

Qualcomm Innovation Fellowship Honorable Mention, Team Fellowship with Brad Campbell, $50,000 (2013–2014)

National Defense Science & Engineering Graduate Fellowship, $95,000 plus tuition (2013–2016)

National Science Foundation Graduate Research Fellowship, $90,000 plus tuition (2013, declined)

University of Michigan Department of Computer Science First-Year Fellowship (2012–2013)

Best Undergraduate Instructor, University of Michigan, EECS (2011–2012)

Invited Presentations

Invited Talk: MBus: A power-aware interconnect for ultra-low power micro-scale system design, at DARPA Near Zero Power RF and Sensor Operations (N-ZERO) Program Review (2016)

Invited Talk: Ultra-Wideband and Indoor Localization, at HotWireless'16

Keynote Address: The Recent Past and Distant Future of [Micro-Scale] Embedded Systems, at NextMote: Next Generation Platforms for the Cyber-Physical Internet, part of the International Conference on Embedded Wireless Systems and Networks (EWSN'16)

PolyPoint and the First Steps Towards Ubiquitous Localization, at the Student Summit on Mobility, Systems, and Networking, Microsoft Research

Guest Speaker: Sensor Systems and the Art of Effectively Deploying Sensor Networks, TechChange TC111: Technology for Monitoring and Evaluation

Invited Talk: Embedded System Design and the Internet of Things, Stanford Internet of Things Industrial Research Program

Invited Talk: Sensing Technologies for Data Collection and Monitoring, State of the Science, Development Impact Lab (DIL) and USAID Higher Education Solutions Network (HESN)

MBus: Enabling the Next Generation of Sensors and Systems, TerraSwarm Annual Meeting

Teaching

Primary Instructor, EECS 398: Computing for Computer Scientists (F'16, W'16)

> A new class designed and built from scratch. This class attempts to address the experience gap that exists across the spectrum of incoming Computer Science students. While driven by tools (shells, build systems, debuggers, version control), it explores how and why computer scientists interface with computers differently in their day-to-day activities, how to apply principles learned in courses to everyday activities, and ultimately how to be a more efficient user of computing resources.
>
> https://c4cs.github.io
>
> *In 2017, I was awarded the Rackham Graduate School Outstanding Graduate Student Instructor and the College of Engineering Richard & Eleanor Towner Prize for Outstanding Graduate Student Instructors for this course.*

Graduate Teaching Assistant, EECS 373: Design of Microprocessor Based Systems (F'15, W'15)

Undergraduate Teaching Assistant, EECS 470: Computer Architecture (W'12)

Undergraduate Teaching Assistant, EECS 482: Introduction to Operating Systems (W'12, F'11, W'11, F'10)

Undergraduate Teaching Assistant, EECS 373: Design of Microprocessor Based Systems (F'11, W'11)

Professional Service

2014 ACM Workshop on Visible Light Communication Systems – Demo Co-Chair

Recurring reviewer for IEEE Transactions on Circuits and Systems II (TCAS-II) *2013–present*

Recurring reviewer for IEEE Transactions on Mobile Computing (TMC) *2014–present*

Recurring reviewer for USAID Development Innovation Ventures (DIV) *2015–present*

Computer Science Engineering Graduate Student Body President *2013–2015*

Computer Science Engineering Student Faculty Representative *2015–2016*

JOURNAL PUBLICATIONS

[1] **Pat Pannuto**, Benjamin Kempke, Li-Xuan Chuo, David Blaauw, and Prabal Dutta. "Harmonium: Ultra Wideband Pulse Generation with Bandstitched Recovery for Fast, Accurate, and Robust Indoor Localization". In: *Transactions on Sensor Networks* (2018). **Invited Paper (Under Submission).**

[2] Inhee Lee, Ye-Sheng Kuo, **Pat Pannuto**, Gyouho Kim, ZhiYoong Foo, Ben Kempke, Seokhyeon Jeong, Yejoong Kim, Prabal Dutta, David Blaauw, and Yoonmyung Lee. "MBus: A Fully Synthesizable Low-power Portable Interconnect Bus for Millimeter-scale Sensor Systems". In: *Journal of Semiconductor Technology and Science* 16.6 (Dec. 2016), pp. 745–753. DOI: 10.5573/JSTS.2016.16.6.745.

[3] **Pat Pannuto**, Yoonmyung Lee, Ye-Sheng Kuo, ZhiYoong Foo, Benjamin Kempke, Gyouho Kim, Ronald G. Dreslinski, David Blaauw, and Prabal Dutta. "MBus: A System Integration Bus for the Modular Micro-Scale Computing Class". In: vol. 37. Micro Top Picks 3. May 2016. **Top Pick in Computer Architecture.**

[4] Benjamin Kempke, **Pat Pannuto**, and Prabal Dutta. "Harmonia: Wideband Spreading for Accurate Indoor RF Localization". In: *SIGMOBILE Mobile Computing and Communications Review*. MC²R 18.3 (Jan. 2015), pp. 19–25. ISSN: 1559-1662. DOI: 10.1145/2721896.2721901. URL: http://doi.acm.org/10.1145/2721896.2721901. **Invited Paper.**

[5] Yoonmyung Lee, Suyoung Bang, Inhee Lee, Yejoong Kim, Gyouho Kim, Mohammad Hassan Ghaed, **Pat Pannuto**, Prabal Dutta, Dennis Sylvester, and David Blaauw. "A Modular 1 mm³ Die-Stacked Sensing Platform with Low Power I²C Inter-die Communication and Multi-Modal Energy Harvesting". In: *IEEE Journal of Solid-State Circuits*. Vol. 48. 2013.

CONFERENCE PUBLICATIONS

[6] **Pat Pannuto**, Benjamin Kempke, and Prabal Dutta. "Slocalization: Sub-µW, Static, Decimeter-Accurate Localization with Ultra Wideband Backscatter". In: *Proceedings of the 17th ACM/IEEE International Conference on Information Processing in Sensor Networks*. IPSN'18. New York, NY, USA: ACM, Apr. 2018.

[7] Joshua Adkins, Bradford Campbell, Branden Ghena, Neal Jackson, **Pat Pannuto**, Samuel Rohrer, and Prabal Dutta. "The Signpost Platform for City-Scale Sensing". In: *Proceedings of the 17th ACM/IEEE International Conference on Information Processing in Sensor Networks*. IPSN'18. New York, NY, USA: ACM, Apr. 2018.

[8] Amit Levy, Bradford Campbell, Branden Ghena, Daniel B. Giffin, **Pat Pannuto**, Prabal Dutta, and Philip Levis. "Multiprogramming a 64kB Computer Safely and Efficiently". In: *Proceedings of the 26th Symposium on Operating Systems Principles*. SOSP'17. Shanghai, China: ACM, Oct. 2017, pp. 234–251. ISBN: 978-1-4503-5085-3. DOI: 10.1145/3132747.3132786. URL: http://doi.acm.org/10.1145/3132747.3132786.

[9] Benjamin Kempke, **Pat Pannuto**, Bradford Campbell, and Prabal Dutta. "SurePoint: Exploiting Ultra Wideband Flooding and Diversity to Provide Robust, Scalable, High-Fidelity Indoor Localization". In: *Proceedings of the 14th ACM Conference on Embedded Networked Sensor Systems*. SenSys'16. Stanford, CA, USA, Nov. 2016. Acceptance: 21 / 119 (18%).

[10] Benjamin Kempke, **Pat Pannuto**, and Prabal Dutta. "Harmonium: Asymmetric, Bandstitched UWB for Fast, Accurate, and Robust Indoor Localization". In: *Proceedings of the 15th International Conference on Information Processing in Sensor Networks*. IPSN'16. Vienna, Austria, Apr. 2016. Acceptance: 23 / 117 (20%).

[11] **Pat Pannuto**, Yoonmyung Lee, Ye-Sheng Kuo, ZhiYoong Foo, Benjamin Kempke, Gyouho Kim, Ronald G. Dreslinski, David Blaauw, and Prabal Dutta. "MBus: An Ultra-Low Power Interconnect Bus for Next Generation Nanopower Systems". In: *Proceedings of the 42nd International Symposium on Computer Architecture*. ISCA '15. Portland, Oregon, USA: ACM, June 2015. Acceptance: 58 / 305 (19%).

[12] William Huang, Ye-Sheng Kuo, **Pat Pannuto**, and Prabal Dutta. "Opo: A Wearable Sensor for Capturing High-Fidelity Face-to-Face Interactions". In: *Proceedings of the 12th ACM Conference on Embedded Networked Sensor Systems*. SenSys '14. Memphis, Tennessee, USA: ACM, 2014. ISBN: 978-1-4503-3143-2. Acceptance: 21 / 117 (18%).

[13] Ye-Sheng Kuo, **Pat Pannuto**, Gyouho Kim, ZhiYoong Foo, Inhee Lee, Benjamin Kempke, Prabal Dutta, David Blaauw, and Yoonmyung Lee. "MBus: A 17.5 pJ/bit Portable Interconnect Bus for Millimeter-Scale Sensor Systems with 8 nW Standby Power". In: *CICC '14: IEEE Custom Integrated Circuits Conference*. San Jose, California, USA, Sept. 2014. Acceptance: 94 / 266 (35%).

[14] Ye-Sheng Kuo, **Pat Pannuto**, Ko-Jen Hsiao, and Prabal Dutta. "Luxapose: Indoor Positioning with Mobile Phones and Visible Light". In: *The 20th Annual International Conference on Mobile Computing and Networking*. MobiCom '14. Maui, Hawaii, USA, Sept. 2014. Acceptance: 36 / 220 (16%).

[15] David Blaauw, Dennis Sylvester, Prabal Dutta, Yoonmyung Lee, Inhee Lee, Sechang Bang, Yejoong Kim, Gyouho Kim, **Pat Pannuto**, Ye-Sheng Kuo, Dongmin Yoon, Wanyeong Jung, ZhiYoong Foo, Yen-Po Chen, Jeong Seok-Hyeon, and Myungjoon Choi. "IoT Design Space Challenges: Circuits and Systems". In: *Proceedings of the 2014 IEEE Symposium on VLSI Technology (VLSI'14)*. Honolulu, Hawaii, USA, June 2014. **Invited Paper.**

[16] Gyouho Kim, ZhiYoong Foo, **Pat Pannuto**, Ye-Sheng Kuo, Benjamin Kempke, Mohammad Hassan Ghaed, Suyoung Bang, Inhee Lee, Yejoong Kim, Seokhyeon Jeong, Prabal Dutta, Dennis Sylvester, and David Blaauw. "A Millimeter-Scale Wireless Imaging System with Continuous Motion Detection and Energy Harvesting". In: *VLSI Circuits (VLSIC), 2014 Symposium on*. Honolulu, Hawaii, USA, June 2014. Acceptance: 96 / 420 (23%).

[17] Ye-Sheng Kuo, **Pat Pannuto**, Thomas Schmid, and Prabal Dutta. "Reconfiguring the Software Radio to Improve Power, Price, and Portability". In: *Proceedings of the 10th ACM Conference on Embedded Networked Sensor Systems*. SenSys '12. Toronto, Canada: ACM, 2012. Acceptance: 23 / 123 (19%).

Workshop Publications

[18] Joshua Adkins, Bradford Campbell, Branden Ghena, Neal Jackson, **Pat Pannuto**, and Prabal Dutta. "Energy Isolation Required for Multi-tenant Energy Harvesting Platforms". In: *Proceedings of the Fifth ACM International Workshop on Energy Harvesting and Energy-Neutral Sensing Systems*. ENSsys'17. Delft, Netherlands: ACM, Nov. 2017, pp. 27–30. ISBN: 978-1-4503-5477-6. DOI: 10.1145/3142992.3142995. URL: http://doi.acm.org/10.1145/3142992.3142995. Acceptance: 6 / 18 (33%).

[19] Amit Levy, Bradford Campbell, Branden Ghena, **Pat Pannuto**, Prabal Dutta, and Philip Levis. "The Case for Writing a Kernel in Rust". In: *Proceedings of the 8th Asia-Pacific Workshop on Systems*. APSys '17. Mumbai, India: ACM, Sept. 2017, 1:1–1:7. ISBN: 978-1-4503-5197-3. DOI: 10.1145/3124680.3124717. URL: http://doi.acm.org/10.1145/3124680.3124717.

[20] Amit Levy, Michael P Andersen, Bradford Campbell, David Culler, Prabal Dutta, Branden Ghena, Philip Levis, and **Pat Pannuto**. "Ownership is Theft: Experiences Building an Embedded OS in Rust". In: *Proceedings of the 8th Workshop on Programming Languages and Operating Systems*. PLOS 2015. Monterey, CA: ACM, Oct. 2015. ISBN: 978-1-4503-3942-1. DOI: 10.1145/2818302.2818306. URL: http://dx.doi.org/10.1145/2818302.2818306. Acceptance: 7 / 16 (44%).

[21] Benjamin Kempke, **Pat Pannuto**, and Prabal Dutta. "PolyPoint: Guiding Indoor Quadrotors with Ultra-Wideband Localization". In: *2015 ACM Workshop on Hot Topics in Wireless*. HotWireless '15. Paris, France, Sept. 2015. **Potential for Test of Time 2025 Award.**

[22] **Pat Pannuto**, Yoonmyung Lee, ZhiYoong Foo, Gyouho Kim, David Blaauw, and Prabal Dutta. "Lessons from Five Years of Making Michigan Micro Motes". In: *6th Workshop of Architectural Research Prototyping*. WARP '15. Portland, Oregon, USA, 2015. Acceptance: 11 / 20 (55%).

[23] Bradford Campbell, **Pat Pannuto**, and Prabal Dutta. "Interfacing the Internet of a Trillion Things". In: *The Second International Workshop on the Swarm at the Edge of the Cloud*. SEC '15. Seattle, Washington, USA, 2015.

[24] Benjamin Kempke, **Pat Pannuto**, and Prabal Dutta. "Harmonia: Wideband Spreading for Accurate Indoor RF Localization". In: *2014 ACM Workshop on Hot Topics in Wireless*. HotWireless '14. Maui, Hawaii, USA, Sept. 2014.

[25] Ye-Sheng Kuo, **Pat Pannuto**, and Prabal Dutta. "System Architecture Directions for a Software-Defined Lighting Infrastructure". In: *1st ACM Workshop on Visible Light Communication Systems*. VLCS '14. Maui, Hawaii, USA, Sept. 2014.

[26] Noah Klugman, Javier Rosa, **Pat Pannuto**, Matthew Podolsky, William Huang, and Prabal Dutta. "Grid Watch: Mapping Blackouts with Smart Phones". In: *Proceedings of the 15th Workshop on Mobile Computing Systems and Applications*. HotMobile '14. Santa Barbara, California: ACM, Feb. 2014.

[27] **Pat Pannuto** and Prabal Dutta. "Exploring Powerline Networking for the Smart Building". In: *Extending the Internet to Low power and Lossy Networks*. IP+SN '11. Chicago, Illinois, USA, Apr. 2011.

Posters and Demos

[28] Joshua Adkins, Bradford Campbell, Branden Ghena, Neal Jackson, **Pat Pannuto**, Samuel Rohrer, and Prabal Dutta. "Demo Abstract: Applications on the Signpost Platform for City-Scale Sensing". In: *Proceedings of the 17th ACM/IEEE International Conference on Information Processing in Sensor Networks*. IPSN'18. New York, NY, USA: ACM, Apr. 2018.

[29] Joshua Adkins, Bradford Campbell, Branden Ghena, Neal Jackson, **Pat Pannuto**, and Prabal Dutta. "The Signpost Platform for City-Scale Sensing". In: *TerraSwarm 2017 Annual Review*. TerraSwarm'17. Berkeley, CA, USA, Oct. 2017. **David Wessel Best Demo Award.**

[30] Benjamin Kempke, **Pat Pannuto**, Bradford Campbell, and Prabal Dutta. "SurePoint: Exploiting Ultra Wideband Flooding and Diversity to Provide Robust, Scalable, High-Fidelity Indoor Localization". In: *Proceedings of the 14th ACM Conference on Embedded Networked Sensor Systems*. SenSys'16. Stanford, CA, USA, Nov. 2016.

[31] **Pat Pannuto**. "Accessors and the RoboCafé: Interoperability in the Internet of Things". In: *Twelfth International Nanotechnology Conference on Communication and Cooperation*. INC12. Leuven, Belgium, May 2016. **Outstanding Poster Award.**

[32] Benjamin Kempke, **Pat Pannuto**, Bradford Campbell, Joshua Adkins, and Prabal Dutta. "PolyPoint: High-Precision Indoor Localization with UWB". In: *Proceedings of the 13th ACM Conference on Embedded Networked Sensor Systems*. SenSys'15. Soeul, Republic of Korea, Nov. 2015.

[33] **Pat Pannuto**, Michael P Andersen, Tom Bauer, Bradford Campbell, Amit Levy, David Culler, Philip Levis, and Prabal Dutta. "Poster Abstract: A Networked Embedded System Platform for the Post-Mote Era". In: *Proceedings of the 12th ACM Conference on Embedded Networked Sensor Systems*. SenSys '14. Memphis, Tennessee, USA: ACM, 2014.

[34] Ye-Sheng Kuo, **Pat Pannuto**, and Prabal Dutta. "Demo — Luxapose: Indoor Positioning with Mobile Phones and Visible Light". In: *The 20th Annual International Conference on Mobile Computing and Networking*. MobiCom '14. Maui, Hawaii, USA, Sept. 2014.

[35] Ye-Sheng Kuo, **Pat Pannuto**, and Prabal Dutta. "Demo — Luxapose: Indoor Positioning with Mobile Phones and Visible Light". In: *1st ACM Workshop on Visible Light Communication Systems*. VLCS '14. Maui, Hawaii, USA, Sept. 2014.

[36] **Pat Pannuto**, Yoonmyung Lee, ZhiYoong Foo, David Blaauw, and Prabal Dutta. "Demo: M3: A Mm-scale Wireless Energy Harvesting Sensor Platform". In: *Proceedings of the 1st International Workshop on Energy Neutral Sensing Systems*. ENSSys '13. Rome, Italy: ACM, Nov. 2013, 17:1–17:2. ISBN: 978-1-4503-2432-8. DOI: [10.1145/2534208.2534225](https://doi.org/10.1145/2534208.2534225).

[37] **Pat Pannuto**, Bradford Campbell, and Prabal Dutta. "GATD: A Robust, Extensible, Versatile Swarm Dataplane". In: *The First International Workshop on the Swarm at the Edge of the Cloud*. SEC '13. Montreal, Quebec, Canada, 2013.

[38] Ye-Sheng Kuo, **Pat Pannuto**, and Prabal Dutta. "Demo: Floodcasting, a Data Dissemination Service Supporting Real-time Actuation and Control". In: *Proceeding of the 11th Annual International Conference on Mobile Systems, Applications, and Services*. MobiSys '13. Taipei, Taiwan: ACM, June 2013, pp. 489–490. ISBN: 978-1-4503-1672-9. DOI: [10.1145/2462456.2465697](https://doi.org/10.1145/2462456.2465697).

[39] **Pat Pannuto**, Prabal Dutta, Bradford Campbell, Samuel DeBruin, Trey Grunnagle, William Huang, Ben Kempke, Ye-Sheng Kuo, Andrew Robinson, Aaron Schulman, Maya Spivak, and Lohit Yerva. "Platforms and Protocols for Emerging Wireless Systems". In: Future of Mobile Computing Workshop. Mountain View, California: Google, 2012.

[40] **Pat Pannuto**, Yoonmyung Lee, Ben Kempke, Dennis Sylvester, David Blaauw, and Prabal Dutta. "Demo: Ultra-constrained sensor platform interfacing". In: *Proceedings of the 11th international conference on Information Processing in Sensor Networks*. IPSN '12. Beijing, China: ACM, Apr. 2012, pp. 147–148. ISBN: 978-1-4503-1227-1. DOI: [10.1145/2185677.2185721](https://doi.org/10.1145/2185677.2185721).