

MICHAEL R. ZINN, PH.D.

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EDUCATION

Stanford University (Stanford, California)

Ph.D. Mechanical Engineering, Stanford Robotics Laboratory (2005)

Dissertation Title: "A New Actuation Approach for Human-Friendly Robotic Manipulation."

Massachusetts Institute of Technology (Cambridge, Massachusetts)

M.S. Civil Engineering, Structural Facilities Division

Thesis Title: "Wave Propagation in Circumferential Anisotropic Media"

B.S. Civil Engineering, Structural Facilities Division

RESEARCH EXPERIENCE

Associate Professor, Department of Mechanical Engineering, University of Wisconsin – Madison (2014-present)

Assistant Professor, Department of Mechanical Engineering, University of Wisconsin – Madison (2007-2014)

Director – REACH Lab (Robotics Engineering, Applied Controls and Haptics Lab

(www.reach.wisc.edu)

Research interests are broadly directed at understanding and overcoming the design and control challenges of complex electro-mechanical systems with a primary focus on human-centered robotics. Research focus on human-centered robotics spans multiple application areas including manufacturing, medical devices, and haptics.

Research Assistant, Stanford Robotics Laboratory, Stanford University (2000-2003)

Study Title: Design and Development of a Testbed for a New Generation of Robots for Human Environments (NSF Grant EIA-9977717) (1999-2005)

Developed a new integrated manipulator-actuation approach for human-centered robotics possessing characteristics necessary to achieve inherent safety and high performance.

- ◆ Developed and designed a first-generation human-friendly dual-arm robotic platform, combining low impedance actuator and manipulator characteristics with high-bandwidth torque control to produce an inherently safe, high-performance robotic system.
- ◆ Developed an analytical framework for the optimization, characterization, and control of low impedance, high-performance robotic manipulators incorporating the Distributed Macro-Mini Actuation technology
- ◆ Designed a dual-arm six-axis robotic manipulator. Performed the mechanical, actuation, sensor, and control system design and integration.
- ◆ Performed project management tasks including the supervision of Masters and Engineer students supporting the project, authoring of annual summary reports, status presentations and follow-on project funding proposals.

Dissertation Advisor: Prof. Bernard Roth, Design Division, Dept. of Mechanical Engineering

Dissertation Advisor: Prof. Oussama Khatib, Stanford Robotics Lab, Dept. of Computer Science

Reading Committee: Prof. J. Kenneth Salisbury, Stanford Robotics Lab, Dept. of Computer Science

Research Assistant, Civil Engineering, Massachusetts Institute of Technology (1987-1988)

Study Title: Wave Propagation in Anisotropic Media (1987-1988)

- ◆ Developed the mathematical framework for wave propagation in circumferentially anisotropic media through the partial-discretization of the wave equation along the anisotropic radial direction.
- ◆ Developed computer simulation for the analysis and visualization of three-dimensional wave propagation

Thesis Advisor: Professor Edwardo Kausal, Department of Civil Engineering

PROFESSIONAL EXPERIENCE:

HANSEN MEDICAL (2003-2007)

Director, Systems/Controls Engineering

Led the controls and system architecture design effort for the world's first commercially-available minimally invasive tele-robotic catheter system.

- ◆ Managed controls and systems groups, overseeing the development of the system kinematics, servo-controls, haptics, and integrated visualization subsystems.
- ◆ Chief systems and controls architect, responsible for overall architecture design and implementation
- ◆ Completed full systems and controls product development life-cycle including initial prototyping, system and subsystem design and implementation, system verification and validation, system clinical trials, regulatory approval (pending) and final product launch.
- ◆ Developed the non-linear kinematics and control topology for a multi-degree-of-freedom flexible robotic catheter, enabling precise and stable end-effector control and placement
- ◆ Managed the technical development of Hansen's proprietary catheter force-sensing technology, including the mechanical, controls, and algorithm subsystems. The force sensing technology substantially contributed to the safety and efficacy of the catheter system.

LOCKHEED-MARTIN MISSILES & SPACE (1988-2001)

Mass Trim Mechanism: NASA Gravity Probe B Satellite Program

Project Manager / Sr. Design Engineer (10/98–3/01)

Managed the design, assembly, and testing of a six-axis satellite mass balancing system.

- ◆ Ultra-low vibration disturbance requirement verified using innovative testing and data analysis techniques. An Integrated data acquisition and processing test bed achieved an order of magnitude improvement in existing measurement resolution while reducing fixture and instrumentation costs. Results published at the 33rd Aerospace Mechanisms Symposium (1999).
- ◆ High fidelity actuator and sensor design trade, utilizing advanced simulation and analysis techniques, allowed for the use of a simplified actuation and sensing system – greatly reducing system complexity and cost.
- ◆ Mechanism designed for very high reliability. Design exceeded environmental and life cycle requirements by a factor of two allowing for reduced flight unit and integration testing
- ◆ Use of master-slave tooling – interchangeable design at system and component level – allowed compression of order of magnitude improvement in existing measurement resolution while reducing fixture and instrumentation costs. Results published at the 33rd Aerospace Mechanisms Symposium (1999)
- ◆ Implemented innovative front-loaded testing strategy, reducing estimated development cost by more than 30% while substantially reducing late-stage program schedule risk

- ◆ Reduced flight unit costs and managed limited engineering manpower resources through aggressive subcontracting of manufacturing and final assembly tasks

Launch Release Mechanism: NASA Gravity Probe B Satellite Program Project Manager / Sr. Design Engineer (10/98–3/01)

Managed the design, manufacture, and testing, from initial prototype through final integration, of nitinol actuated high G-load launch load restraint system.

- ◆ Aggressive use of computer analysis tools and upfront development testing allowed the use of a cost-effective, reliable, but highly nonlinear nitinol actuation system which drastically reduced the need for limited power resources while improving mechanism function and reliability
- ◆ Innovative design mitigated potential mission failure event, allowing for the use of existing flight hardware and averting a six month schedule delay.
- ◆ Use of master-slave tooling – interchangeable design at system and component level – allowed compression of schedule through fast-tracking of manufacturing and testing process.
- ◆ Introduced integrated product team principles - integrating design, manufacturing, procurement, and operations personnel into single, project focused team.

Deployable Antenna Integration: MSAT Satellite Program Team Lead / Sr. Design Engineer (1/94–6/96)

Directed the manufacturing integration and alignment of a 40 foot deployable spacecraft antenna and boom subsystem for Lockheed-Martin's first commercial fixed-price satellite program

- ◆ Led the design, manufacture, and implementation of a suite of high precision alignment and metrology tooling used in the integration of the antenna assembly
- ◆ Met stringent sub arc-minute alignment requirements through the use of integrated master-slave tooling and stochastic error analysis, achieving alignment accuracy below one arc-minute for the first time for a deployable antenna of this size. Results published at the 28th Aerospace Mechanisms Symposium (1997)
- ◆ Managed alignment and integration product team group through two-year antenna integration including testing, verification and final assembly
- ◆ Met rigid budget and schedule constraints of LMMS first commercial satellite project. Compressed integration schedule by more than 50% from original contract estimate, reducing program costs more than 1 million dollars.

Solar Array Deployment Mechanism Failure Investigation Sr. Research Engineer (1/93-1/94)

Led the failure investigation of a multi-billion dollar spacecraft solar array deployment mechanism

- ◆ Uncovered previously unknown in-flight failure mode. Subsequent corrective action avoided a mission ending failure to a multi-billion dollar satellite program
- ◆ Developed analysis and simulation methods to uncover potential future failure risks. Success of analysis effort led to its application corporate-wide. Results published at the 27th Aerospace Mechanisms Symposium (1993)
- ◆ Awarded prestigious Lockheed PIP award for success of failure investigation

NASA Advanced Bearing Mechanism Research Study Research Engineer (6/91-1/93)

Led the design and analysis effort of a NASA sponsored advanced bearing technology research project

- ◆ Directed the concept validation and design of a new high precision gimbal drive system which incorporated a hybrid ball bearing/flexure pivot design with active torsion

disturbance isolation. This work established the company as a leader in high precision spacecraft gimbal technology

- ◆ Developed advanced simulation and analysis methods to investigate the performance limits of high precision pointing instruments. Summary report and presentation was specifically cited by the customer as a key factor in the award of a follow-on contract of more than \$1 million

PUBLICATIONS

Journals / Refereed archival conference publications:

1. Guru Subramani, Michael Gleicher, Michael Zinn, "Recognizing Geometric Constraints in Human Demonstrations using Force and Position Signals", *IEEE International Conference on Robotics and Automation (ICRA)*, Brisbane, Australia, May 2018.
2. Chembian Parthiban, Michael Zinn, "Performance and Stability Limitations of Admittance-based Haptic Interfaces", *IEEE Haptics Symposium 2018*, San Francisco, CA, March 2018.
3. Guru Subramani, Michael Zinn, Michael Gleicher, "Recognizing Force Events with the Complex Morlet Wavelet", *IEEE International Conference on Robotics and Systems (IROS 2017)*, Vancouver, BC, Canada, September 2017.
4. Franke, Daniel, Morrow, Justin D., Duffie, Neil A., Zinn, Michael, Pfefferkorn, Frank E., "Solid State Infiltration of 6061-T6 Aluminum Alloy into Carbon Fibers via Friction Stir Welding", *ASME Journal of Manufacturing Science and Engineering*, 139(11), Sept 2017.
5. Amber Shrivastava, Michael Zinn, Neil A. Duffie, Nicola J. Ferrier, Christopher B. Smith, Frank E. Pfefferkorn, "Force measurement-based discontinuity detection during friction stir welding", *SME Journal of Manufacturing Processes*, 26 (2017) 113–121.
6. Conrad, B., Zinn, M., "Interleaved Continuum-Rigid Manipulation: An Approach to Increase the Capability of Minimally-Invasive Surgical System", *ASME/IEEE Transactions on Mechatronics*, 22(1), September 2016
7. J. Guenther, D. Farley, H. Ploeg, M. Zinn, "Feedback Control for Patient Specific Limb Lengthening and Limb Deformity Correction", *Journal of Medical Devices, Transaction of the ASME*, Vol. 9, September 2015.
8. Farley, M. Zinn, H. Ploeg, "Evaluation of Extension Mechanism in an Implantable Limb Lengthening Device", *Journal of Medical Devices, Transaction of the ASME*, Vol. 9, September 2015.
9. Shrivastava, A., Dingler, C., Zinn, M., Pfefferkorn, F., "Physics-based interpretation of tool-workpiece interface temperature signals for detection of defect formation during friction stir welding", *Manufacturing Letters*, Volume 5, August 2015, Pages 7-11
10. A. Shrivastava, F. Pfefferkorn, N. Duffie, N. Ferrier, C. Smith, K. Malukhin, M. Zinn, "Physics-based process model approach for detecting discontinuity during friction stir welding", *International Journal of Advanced Manufacturing Technology*, 79(1), pp 605–614, July 2015.
11. Conrad, B., Zinn*, M.R., "Closed Loop Task Space Control of an Interleaved Continuum-Rigid Manipulator ", *IEEE International Conference of Robotics and Automation*, 26-30 May 2015, Seattle, WA, pp 1743 - 1750, (acceptance rate: 35%).
12. Borgstadt, J.A., Ferrier, N.J., Zinn*, M.R., "Multi-Modal Localization Algorithm for Catheter Interventions", *IEEE International Conference of Robotics and Automation*, 26-30 May 2015, Seattle, WA, pp 5350 - 5357, (acceptance rate: 35%).
13. Subramani, G., Zinn*, M.R., "Tackling Friction – An Analytical Modeling Approach to Understanding Friction in Single Tendon Driven Continuum Manipulators", *IEEE International Conference of Robotics and Automation*, 26-30 May 2015, Seattle, WA, pp 610-617, (acceptance rate: 35%).
14. Penning, R.S., Zinn, M.R., "A Combined Modal-Joint Space Control Approach for Minimally Invasive Surgical Continuum Manipulators", *Advanced Robotics*, Vol. 28, Issue 16, pp. 1091-1108, August 2014.

15. Daniel Farley, Heidi Ploeg, Michael Zinn, "Towards A Novel, Implantable Limb Lengthening Device", *ASME Journal of Medical Devices*, Vol. 8, Issue 2, April 2014.
16. Cole, E.G., Fehrenbacher, A., Duffie, N.A., Zinn, M.R., Pfefferkorn, F.E., Ferrier*, N.J., "Weld Temperature Effects during Friction Stir Welding of Dissimilar Aluminum Alloys 6061-T6 and 7075-T6", *International Journal of Advanced Manufacturing Technology*, Vol 71, Issue 1-4, pp. 643-652, March 2014.
17. J. Jung, Penning, R., M.R. Zinn, 2014, "A Modeling Approach for Continuum Robotic Catheters: Effects of Nonlinear Internal Device Friction," *Advanced Robotics*, Vol 28, Issue 8, pp 557-572, 2014.
18. Fehrenbacher, A., Schmale, J., Zinn, M.R., Pfefferkorn, F.E., "Measurement of Tool-Workpiece Interface Temperature Distribution in Friction Stir Welding", *ASME Journal of Manufacturing Science and Engineering*, Vol. 136, Issue 2, Jan 2014.
19. Conrad, B.L., Zinn, M.R., "Interleaved Continuum-Rigid Manipulation Approach: Development and Functional Evaluation of a Clinical Scale Manipulator", *Intelligent Robots and Systems (IROS 2014)*, 2014 *IEEE/RSJ International Conference on*, pp. 4290-4296, Chicago, IL.
20. Fehrenbacher, A., Duffie, N.A., Ferrier, N.J., Pfefferkorn, F.E., Zinn, M.R., "Effects of Tool-Workpiece Interface Temperature on Weld Quality and Quality Improvements Through Temperature Control in Friction Stir Welding", *International Journal of Advanced Manufacturing Technology*, Vol. 71, Issue 1-4, pp. 165-179, March 2014.
21. Parthiban, C., Zinn, M.R., "A Simplified Approach to Admittance-type Haptic Device Impedance", *2014 IEEE Haptics Symposium*, Houston, TX, February 2014
22. Axel Fehrenbacher, Christopher B. Smith, Neil A. Duffie, Nicola J. Ferrier, Frank E. Pfefferkorn, Michael R. Zinn, "Combined Temperature and Force Control for Robotic Friction Stir Welding," *ASME Journal of Manufacturing Science and Engineering*, Vol. 136, Issue 2, Jan 2014
23. Esser, C, M, Parthiban, C., M.R. Zinn, "Development of a Parallel Actuation Approach for MR-Compatible Robotics," *IEEE/ASME Transactions on Mechatronics*, 19(3), 904-915, 2013.
24. Conrad, B.L., Jung, J., Penning, R.S., Zinn, M.R., "Interleaved Continuum-Rigid Manipulation: An Augmented Approach For Robotic Minimally-Invasive Flexible Catheter-based Procedures", *IEEE International Conference on Robotics and Automation*, Karlsruhe, Germany, May 6-10, 2013 (refereed proceedings: acceptance rate 35%)
25. Shultz, E.F., A. Fehrenbacher, F.E. Pfefferkorn, M.R. Zinn, N.J. Ferrier, "Shared Control of Robotic Friction Stir Welding in the Presence of Imperfect Joint Fit-Up," *Journal of Manufacturing Processes*, Volume 15, Issue 1, January 2013, Pages 25–33.
26. Penning, R., J. Jung, N.J. Ferrier, M.R. Zinn, "An Evaluation of Closed-Loop Control Options for Continuum Manipulators," *IEEE International Conference on Robotics and Automation*, St-Paul, Minnesota, May 14-18, 2012, DOI 10.1109/ICRA.2012.6224735, (refereed proceedings: acceptance rate 38%).
27. Myung-Sin Cho, Hyun-Su Hwang, Min-Hyoung Lee, Byungkyu Kim, and Michael R. Zinn, "A Screw Jack Mechanism-based Separation Device Driven by a Piezo Actuator", *International Journal of Precision Engineering and Manufacturing*, Volume 13, Issue 11, pp 2079-2082
28. Parthiban, Chembian, Esser, C, M, M.R. Zinn, "Evaluation of a Parallel Actuation Approach for MR-Compatible Haptics," *2012 IEEE Haptics Symposium*, March 4-7, 2012, Vancouver, Canada, 10.1109/HAPTIC.2012.6183848.
29. Edward G Cole, Axel Fehrenbacher, Edward F Shultz, Christopher B Smith, Nicola J Ferrier, Michael R Zinn, Frank E Pfefferkorn, "Stability of the Friction Stir Welding Process in Presence of Workpiece Mating Variations", *International Journal of Advanced Manufacturing Technology*, February, 2012
30. Fehrenbacher, A., Neil A. Duffie, Nicola J. Ferrier, Frank E. Pfefferkorn, Michael R. Zinn, "Toward Automation of Friction Stir Welding Through Temperature Measurement and Closed-Loop Control," *ASME Journal of Manufacturing Science and Engineering*, October 2011, Volume 133, Issue 5

31. J. Jung, Penning, R., N.J. Ferrier, M.R. Zinn, "A Modeling Approach for Continuum Robotic Manipulators: Effects of Nonlinear Internal Device Friction," *IEEE/RSJ International Conference on Intelligent Robots and Systems*, San Francisco, CA, September 25-30, 2011, DOI 10.1109/IROS.2011.6094941, (refereed proceedings: acceptance rate 32%.)
32. Penning, R., J. Jung, J. Borgstadt, N.J. Ferrier, M.R. Zinn, "Towards Closed Loop Control of a Continuum Robotic Manipulator for Medical Applications," 2011 *IEEE International Conference on Robotics and Automation*. Shanghai, China, May 9-13, 2011, DOI 10.1109/ICRA.2011.5980233, (refereed proceedings: acceptance rate 49%).
33. Esser, C, M, M.R. Zinn, "Development of a Differential Actuator Concept for MR-Compatible Robotic Applications," 3rd *IEEE/RAS-EMBS International Conference on Biomedical Robotics and Biomechanics – BioRob 2010*, Sept 26-29, 2010, Tokyo, Japan, DOI 10.1109/BIOROB.2010.5628003, (refereed proceedings: acceptance rate approximately 50%),
34. Shultz E.F., E.G. Cole, C.B. Smith, M.R. Zinn, N.J. Ferrier, and F.E. Pfefferkorn: "Effect of Compliance and Travel Angle on Friction Stir Welding with Gaps," *ASME Journal of Manufacturing Science and Engineering*, Volume 132, Issue 4, August 2010 DOI:10.1115/1.4001581
35. Zinn, M., Khatib, O., Roth, B., Salisbury, J.K., "Large Workspace Haptic Devices – A New Actuation Approach", *16th Symposium on Haptic Interfaces for Virtual Environments and Teleoperator Systems*, Reno, Nevada, March 2008, DOI 10.1109/HAPTICS.2008.4479941 – (Awarded best paper)
36. Camarillo, D. B.; Milne, C. F.; Carlson, C. R.; Zinn, M. R.; Salisbury, J. K., "Mechanics Modeling of Tendon-Driven Continuum Manipulators", *IEEE Transactions on Robotics*, Vol. 24, No. 6, Dec. 2008, pp. 1262-1273
37. Zinn, M., Roth, B. , Khatib, O., Salisbury, J.K., "New Actuation Approach for Human-Friendly Robot Design", *International Journal of Robotics Research*, Vol. 23, No.4-5, April-May 2004, pp. 379-398
38. Zinn, M., Khatib, O., Roth, B., Salisbury, J.K., "Playing It Safe – A New Actuation Concept for Human Friendly Robot Design", *IEEE Robotics and Automation Magazine*, Vol. 11, No. 2 June 2004
39. Zinn, M., Khatib, O., Roth, B., Salisbury, J.K., "Actuation Methods For Human-Centered Robotics and Associated Control Challenges", *Springer Tracts in Advanced Robotics*, Vol. 4 Control Problems in Robotics, Springer-Verlag 2003, 10.1007/3-540-36224-X_7.

Items at Conferences:

40. Conrad, B., Subramani, G., Zinn, M., "Adaptive Control of an Interleaved Continuum Rigid Manipulator", *IEEE International Conference on Intelligent Robots and Systems*, Workshop on Continuum Robots in Medicine – Design, Integration, and Applications, Vancouver, BC, CA, Sept. 2017.
41. Woong Jo Choi, Justin D. Morrow, Frank E. Pfefferkorn, Michael R. Zinn, "The Effects of Welding Parameters and Backing Plate Diffusivity on Energy Consumption in Friction Stir Welding", *45th SME North American Manufacturing Research Conference, NAMRC 45*, Los Angeles, CA, June 2017.
42. Daniel Franke, Justin Morrow, Michael Zinn, Neil Duffie and Frank Pfefferkorn, "Experimental Determination of the Effective Viscosity of Plasticized Aluminum Alloy 6061-T6 during Friction

- Stir Forming”, *45th SME North American Manufacturing Research Conference, NAMRC 45*, Los Angeles, CA, June 2017.
43. Guru Subramani, Aubrey Fisher, Moria Fisher Bittmann, Andrea H. Mason, Brittany G. Travers, Michael R. Zinn, “Development of a Robotic Motor Skills Assessment System for Children with Autism”, *2017 Design of Medical Devices Conference*, Minneapolis, MN.
 44. Bolun Zhang, Daniel Farley, Heidi-Lynn Ploeg, Michael Zinn, “Validation of Feedback Control Mechanism in an Implantable Limb Lengthening Prototype”, *2017 Design of Medical Devices Conference*, Minneapolis, MN.
 45. Franke, D., Morrow, J., Duffie, N., Zinn, M., Pfefferkorn, F., “Towards Improved Hybrid Joining of Aluminum Alloys to Carbon Fiber Composites with Friction Stir Welding”, *Manufacturing Science and Engineering Conference (MSEC 2016)*, Blacksburg, VA, June 27- July 1, 2016 – awarded BEST PAPER
 46. C. Parthiban, R. Ray, D. Rutherford, M. Zinn, C. Pugh, "Development and Analysis of Psychomotor Skills Metrics for Procedural Skills Decay", *NextMed / MMVR22 - The 22nd Medicine Meets Virtual Reality Conference*, April 7 - 9, 2016, Los Angeles, California.
 47. J. Guenther, D. Farley, H. Ploeg, M. Zinn, "Feedback Control for Patient Specific Limb Lengthening and Limb Deformity Correction", *Design of Medical Devices Conference (DMD2015)*, April 13–16, 2015, Minneapolis, MN, USA.
 48. D. Farley, M. Zinn, H. Ploeg, "Evaluation of Extension Mechanism in an Implantable Limb Lengthening Device", *Design of Medical Devices Conference (DMD2015)*, April 13–16, 2015, Minneapolis, MN, USA.
 49. Farley, D., Zinn, M.R., Ploeg*, H.L., "Towards a Novel, Implantable Limb Lengthening Device", *Limb Lengthening and Reconstruction Society Annual Scientific Meeting*, 2014, Montreal, CA., Jun 2014.
 50. Guenther, J., Farley, D., Ploeg, H.L., Zinn*, M.R., "Feedback Control for Patient-Specific Lengthening of an Implantable Limb Lengthening Device", *Limb Lengthening and Reconstruction Society Annual Scientific Meeting*, 2014, Montreal, CA., Jun 2014.
 51. Amber Shrivastava, Frank Pfefferkorn, Michael Zinn, "Physics-based Process Model Approach for Defect Detection during Friction Stir Welding", *2014 10th International Symposium on Friction Stir Welding*, Beijing, China, accepted January 2014.
 52. Daniel Farley, Heidi Ploeg, Michael Zinn, "A Novel, Implantable Limb Lengthening Device", *2014 Design of Medical Devices Conference*, Minneapolis, MN, accepted January 2014.
 53. Fehrenbacher, A., Smith, C.B., Duffie, N.A., Ferrier, N.J., Pfefferkorn, F.E., Zinn, M.R., “Combined Temperature and Force control for Robotic Friction Stir Welding”, *Proceedings of the ASME 2013 International Manufacturing Science and Engineering Conference*, June 10-14, 2013, Madison, Wisconsin, USA,.
 54. Tetrick, D., Farley, D., Arastoopour, G., Zinn, M., Shaffer, D., Chesler, N., “RescuShell: A Biomechanical Design Epistemic Game for First-Year Engineering Education and Potentially Increased Retention of Women”, *Proceedings of the ASME 2013 Summer Bioengineering Conference*, SBC2013-14069, June 26-29, Sunriver, Oregon, USA.
 55. Sokn, S., Ploeg, H., McCoy, S., Farley, D., Collins, C., Medicherla, A., Zinn, M., McCarthy, J.J., “Novel 3 Degree of Freedom, Minimally Invasive, Implantable Active Bone Correction Device”, *22nd Annual Limb Lengthening and Reconstruction Society Meeting*, Cincinnati, OH, July 2012.
 56. Collins, C., Ploeg, H., McCoy, S., Farley, D., Medicherla, A., Zinn, M., McCarthy, J.J., “A Novel Minimally Invasive Implantable Extramedullary Limb Lengthening Device”, *22nd Annual Limb Lengthening and Reconstruction Society Meeting*, Cincinnati, OH, July 2012.
 57. A. Fehrenbacher, N. A. Duffie, N. J. Ferrier, M. R. Zinn, and F. E. Pfefferkorn, “Tool-Workpiece Interface Temperature Measurement and Improved Closed-Loop Control in Friction Stir Welding,” in *9th International Friction Stir Welding Symposium*, Huntsville, AL, TWI, 2012.
 58. Zinn, M. "Admittance-based Haptic Interface Performance Evaluation and Associated Challenges", *2012 Haptics Symposium*, Vancouver Canada, Panel Workshop: Haptic Hardware Evaluation Practices (invited)

59. A. Fehrenbacher, E. F. Shultz, F. E. Pfefferkorn, M. R. Zinn, N. J. Ferrier, and N. A. Duffie, "Enhancing Friction Stir Welding Through Temperature Control and Shared Human-Computer Control," *TMS Annual Meeting & Exhibition*, San Diego, CA, 2011.
60. Fehrenbacher, Axel, Schmale, Joshua R., Zinn, Michael R., Pfefferkorn, Frank E., "Tool-Workpiece Interface Temperature Measurement in Friction Stir Welding", *ASME 2012 International Manufacturing Science and Engineering Conference*, Notre Dame, Indiana, USA, June 4-8, 2012
61. N.Vlietstra, W. Feyereisen, H. Ploeg, J. Peterman, M. Zinn, J. McCarthy, 2011, "A Novel Minimally-Invasive Implantable Active Bone Deformity Correction Device," *The Limb Lengthening and Reconstruction Society Twentieth Annual Scientific Meeting*. Chicago, July 22-23, 2011.
62. Fehrenbacher, Axel, Cole, Edward G., Zinn, Michael R., Ferrier, Nicola J., Duffie, Neil A. and Pfefferkorn, Frank E., "Towards Process Control of Friction Stir Welding for Different Aluminum Alloys", *The Minerals, Metals & Materials Society*, pp. 381-388, San Diego, CA, Feb. 27-Mar 3, 2011.
63. Fehrenbacher, Axel, Duffie, Neil A., Ferrier, Nicola J., Pfefferkorn, Frank E., Zinn, Michael R., "Enhancing Friction Stir Welding Through Temperature Control", *ASME 2011 International Manufacturing Science and Engineering Conference (MSEC2011-5031)*, Corvallis, Oregon, USA, June 13-17, 2011
64. Smith, C.B., F.E. Pfefferkorn, L.M. Cervený, E.G. Cole, A. Fehrenbacher, N.J. Ferrier, J.F. Hinrichs, E.F. Shultz, D. Wolf, and M.R. Zinn, 2010, "Portable Friction Stir Welding for Assembly of Large Structures," *8th International Friction Stir Welding Symposium*, May 18-20, Timmendorfer Strand, Germany.
65. C. B. Smith, F. Pfefferkorn, E. Cole, A. Fehrenbacher, N. Ferrier, E. Shultz, M. Zinn, L. Cervený, and J. Hinrichs, "Qualification of a Low Force FSW Process for Portable FSW to be Applied to Assembly of Large Structures," *8th International Friction Stir Welding Symposium*, Timmendorfer Strand, Germany, TWI, 2010.
66. Fehrenbacher, A., N.A. Duffie, N.J. Ferrier, M.R. Zinn, and F.E. Pfefferkorn, 2010, "Temperature Measurement and Closed-Loop Control of Friction Stir Welding," *8th International Friction Stir Welding Symposium*, May 18-20, Timmendorfer Strand, Germany.
67. Shultz, E.F., E.G. Cole, C.B. Smith, M.R. Zinn, N.J. Ferrier, and F.E. Pfefferkorn, 2009, "Effect of Compliance and Travel Angle on Friction Stir Welding with Gaps," *ASME Manufacturing Science & Engineering Conference*, Oct. 4-7, West Lafayette, IN. [poster MSEC2009-83491]
68. Shultz, E.F., F.E. Pfefferkorn, C.B. Smith, M.R. Zinn, and N.J. Ferrier, 2008, "Towards a Man-Machine Interface for Flexible Friction Stir Welding," *7th International Friction Stir Welding Symposium*, Awaji Island, Japan, May 20-22.
69. Fehrenbacher, A., F.E. Pfefferkorn, M.R. Zinn, N.J. Ferrier, and N.A. Duffie, 2008, "Closed-Loop Control of Temperature in Friction Stir Welding," *7th International Friction Stir Welding Symposium*, Awaji Island, Japan, May 20-22.
70. Zinn, M., Khatib, O., Roth, B., Salisbury, J.K., "Toward A Human-Centered Intrinsically-Safe Robotic Manipulator" In *Proceedings of 2nd IARP/IEEE-RAS Joint Workshop on Technical Challenge for Robots in Human Environments*, October, 2002 (invited)
71. Zinn, M., Khatib, O., Roth, B., Salisbury, J.K., "New Actuation Approach for Human-Friendly Robotics", *8th International Symposium on Experimental Robotics*, July 2002.
72. Zinn, M., "Design and Development of the Gravity Probe-B Mass Trim Mechanism", *33rd Aerospace Mechanisms Symposium*, Jet Propulsion Laboratory, May 19, 1999.
73. Zinn, M., "Lockup Failure of a Four-Bar Linkage Deployment Mechanism", *27th Aerospace Mechanisms Symposium*, NASA Ames Research Center, May 12, 1993

Patents:

	Title:	Pub. Number:	Issue Date:
1.	Interleaved Manipulator	US 9364289 B2	June 2016

2. Modular Interfaces and Drive Actuation through Barrier (pending application)	US 14074544	Nov 2013
3. Robotic catheter system	US 8394054 B2	Mar 2013
4. Robotic catheter system	US 7972298 B2	Jul 2011
5. Robotic catheter system	US 7974681 B2	Jul 2011
6. Robotic catheter system	4755638 (Japan)	Jul 2010
7. Systeme de catheter robotique	WO 2005087128 A1	Sept 2005
8. Instrument driver for robotic catheter system	US 8021326 B2	Sept 2011
9. Robotic catheter system and methods	US 8052636 B2	Nov 2011
10. Robotic catheter system and methods	US 8257303 B2	Nov 2011
11. Methods using a robotic catheter system	US 7850642	Dec 2010

GRANTS

Extramural Funding:

- Hybrid Actuation Approaches in Haptic Interface Design

Capacity: PI

Sponsor: Oculus Research LLC

Award Amount: \$223,229

Period Covered: 6/1/2017 – 8/31/2018
- NRI: Small: Interleaved Continuum-Rigid Manipulation - Enabling High-Performance and Inherent-Safety in Minimally-Invasive Surgical Procedures

Capacity: PI

Sponsor: National Science Foundation – IIS (NRI)

Award Amount: \$495,154

Period Covered: 9/1/2013 – 8/31/2018
- GOALI: Enabling Real-Time Detection and Identification of Friction Stir Welding Defects Through the Use of Physics-Based Process Dynamic Modeling

Capacity: PI (Co-PIs: C. Smith – Friction Stir Link Inc., F. Pfefferkorn – U.W. Madison, N. Ferrier – U.W. Madison)

Sponsor: National Science Foundation – CMMI (MPM)

Award Amount: \$374,880

Period Covered: 7/15/2013 – 7/16/2017
- Interactive MR Image Guided Intervention (iMR-IGI) for Breast Applications

Capacity: PI (with Co-I: W. Block of UW-Madison and PD/PI: Raymond Harter of Marvel Medtech LLC, Madison, WI)

Sponsor: National Institute of Health – National Cancer Institute – SBIR Phase I

Award Amount: \$300,000 (\$125,000)

Period Covered: 9/15/2012 – 9/15/2013
- TUES-Type 2: First-year Virtual Internships to Increase Persistence of Underrepresented Groups in Engineering: RescuShell and its parent company RescuTek

Capacity: Co-PI (PI: N. Chesler of UW Madison)

Sponsor: National Science Foundation

Award Amount: \$600,000 (\$100,000)

Period Covered: 8/1/2012 – 7/31/2014

6. Portable Friction Stir Welding Technology for Aluminum Fabrication
Capacity: Co-PI (PI: F.E. Pfefferkorn of UW-Madison)
Sponsor: Office of Naval Research (ONR) - STTR Phase II
Award Amount: \$510,975 (\$200,000)
Period Covered: 3/1/2009 – 12/1/2011 (with options)
7. GOALI: Enabling Friction Stir Welding in Unstructured Environments through Process Identification and Shared Control
Capacity: Co-PI (PI: F.E. Pfefferkorn of UW-Madison)
Sponsor: National Science Foundation (CMMI)
Award Amount: \$300,000 (\$125,000)

Intramural Funding

8. Physically-Responsive Collaborative Robot Manipulation
Capacity: Co-PI (PI: Michael Gleicher, Co-PI: Bilge Mutlu – U.W. Madison, Department of Computer Science)
Sponsor: UW2020: WARF Discovery Initiative
Award Amount: \$474,203
Period Covered: 9/1/2016 – 8/31/2018
9. Robotically-Guided Rehabilitation Paradigm for the Treatment of Upper Limb Motor Skill Deficiencies in Children with Autism Spectrum Disorder
Capacity: PI (co-PI: Andrea Mason, Brittany Travers – U.W. Madison School of Education, Department of Kinesthesiology)
Sponsor: UW-Madison Graduate School – Spring Interdisciplinary Competition
Award Amount: \$79,728
Period Covered: 7/1/2015 – 6/30/2016
10. Interleaved Robotic Manipulation: Next Generation MIS Cardiovascular Procedures
Capacity: PI (co-PI: Amish Raval, M.D. – U.W. Madison School of Health)
Sponsor: Industrial & Economic Development Research (IEDR) Program Grant
Award Amount: \$90,000 (\$50,000 IEDR + \$40,000 WARF Tech Transfer RA)
Period Covered: 7/1/2013 – 6/30/2014
11. Enabling Safe Minimally-Invasive Surgical Procedures Through the Use of Interleaved Continuum-Rigid Manipulation
Capacity: PI
Sponsor: UW-Madison Graduate School – Fall Competition
Award Amount: \$36,112
Period Covered: 7/1/2013 – 6/30/2014
12. A Robotic Manipulator Approach for Safety-Critical Minimally-Invasive Surgery
Capacity: PI (co-PI: John Peterman, Simplex Scientific LLC, Middleton, WI)
Sponsor: Industrial & Economic Development Research (IEDR) Program Grant
Award Amount: \$50,000
Period Covered: 7/1/2012 – 6/30/2013
13. An Actuation and Control Approach for MR-Image Guided Robotic Breast Biopsy
Capacity: PI
Sponsor: UW-Madison Graduate School – Fall Competition
Award Amount: \$42,074
Period Covered: 7/1/2012 – 6/30/2013

14. Control of Temperature for Robotic Friction Stir Welding of Dissimilar Alloys
Capacity: co-PI (PI: N. Ferrier, Dept. of Mechanical Engineering, UW-Madison;
co-PI: Frank Pfefferkorn, Dept. of Mechanical Engineering, UW-Madison, Chris Smith, Friction Stir Link, Inc., Waukesha, WI)
Sponsor: Industrial & Economic Development Research (IEDR) Program Grant
Award Amount: \$50,000
Period Covered: 7/1/2011 – 6/30/2012
15. Development of a Control and Monitoring System for an Implantable Bone Deformity Correction Device
Capacity: co-PI (PI: H. Ploeg, Dept. of Mechanical Engineering, UW-Madison; co-PI: John Peterman, Simplex Scientific LLC, Middleton, WI)
Sponsor: Industrial & Economic Development Research (IEDR) Program Grant
Award Amount: \$50,000
Period Covered: 7/1/2011 – 6/30/2012
16. An Actuation and Control Approach for MR-Image Guided Robotic Breast Biopsy
Capacity: PI (co-PI: Ray Harter, Marvel Medtech LLC, Madison, WI)
Sponsor: Industrial & Economic Development Research (IEDR) Program Grant
Award Amount: \$50,000
Period Covered: 7/1/2011 – 6/30/2012
17. Closed-Loop Control of Robotic Catheters for Advanced Interventional Procedures
Capacity: PI
Sponsor: UW-Madison Graduate School – Fall Competition
Award Amount: \$34,418
Period Covered: 7/1/2011 – 6/30/2012
18. Minimally-Invasive Active Bone Deformity Correction Device
Capacity: PI (co-PI: James McCarthy, Dept. of Orthopedic Surgery, UW-Madison; Heidi Ploeg, Dept. of Mechanical Engineering)
Sponsor: Industrial & Economic Development Research (IEDR) Program Grant
Award Amount: \$49,584
Period Covered: 7/1/2010 – 6/30/2011
19. Enabling In-Vivo Feedback Control of Minimally Invasive Tele-robotic Medical Systems through Shared-Control
Capacity: PI
Sponsor: UW-Madison Graduate School - Fall Competition
Award Amount: \$42,535
Period Covered: 9/1/2010 – 8/31/2011
20. Realization of High-Performance and Inherently-Safe Large Workspace Haptics thru Actuation, Sensing, and Control System Development
Capacity: PI
Sponsor: UW-Madison Graduate School - Fall Competition
Award Amount: \$38,000
Period Covered: 9/1/2009 – 8/31/2010
21. MRI-Guided Robotic Biopsy System for Breast Cancer Diagnosis and Treatment
Capacity: PI (Industry co-PI: Ray Harter, Marvel Medtech LLC, Madison, WI)
Sponsor: Industrial & Economic Development Research (IEDR) Program Grant
Award Amount: \$50,000

Period Covered: 7/1/2009 – 6/30/2010

Invited Talks

1. *Controls Focused Design*, Operational Space Symposium, Stanford University, 09/23/2107.
2. Control Challenges: Robotic Catheters and Interleaved Manipulation, Rice University, Department of Mechanical Engineering Seminar, 03/25/2015.
3. Robotic Catheters, Stanford University Medical Robotics Seminar, 04/24/2015.
4. Minimally Invasive Robotic Catheters: Addressing Challenges through Modeling, Control and Design, University of Michigan, Department of Mechanical Engineering Seminar Series, 09/23/2014.
5. Robotic Catheters – Future Directions and Challenges, Design of Medical Devices Conference, Invited / Featured speaker, 04/09/2014
6. Minimally Invasive Robotic Catheters: Addressing Challenges through Modeling, Control, and Design, Case Western Reserve University – Department of Electrical Engineering and Computer Science Seminar Series, 02/13/2014
7. Minimally Invasive Robotic Catheters: Addressing Challenges through Modeling, Control, and Design, University of Wisconsin – Madison, Lindberg Lecture Series, 01/23/2014.
8. Minimally Invasive Robotic Catheters: Addressing Challenges through Modeling, Control, and Design, Johns Hopkins University, NSF ERC for Computer-Integrated Surgical Systems and Technology Seminar Series, 12/04/2013.
9. Minimally Invasive Robotic Catheters: Addressing Challenges through Modeling, Control, and Design, Northwestern University – Department of Mechanical Engineering Seminar, 11/15/2013.
10. Minimally Invasive Robotic Catheters: Addressing Challenges through Modeling, Control, and Design, Clemson University – Department of Electrical & Computer Engineering Seminar Series, 11/07/2013.
11. Early Career Forum – NSF MSEC Panel Discussion, ASME International Manufacturing Science and Engineering Conference, Madison, WI, 05/13/2013.
12. Interleaved Continuum-Rigid Manipulation for MIS Robotic Procedures, University of Wisconsin – Madison Therapeutic Medical Devices seminar, 05/01/2013.
13. Catheter-based Robotic Surgery: Capabilities and Challenges University of Wisconsin – Madison, Therapeutic Medical Devices seminar, 05/02/2012.
14. MRI-Compatible Robotics: Design Challenges, Stanford University Surgical Robotics Seminar, 04/18/2012.
15. Admittance-based Haptic Interface Performance Evaluation and Associated Challenge, 2012 Haptics Symposium, Vancouver Canada, Panel Workshop: Haptic Hardware Evaluation Practices, 03/04/2012.
16. WID-DOW Seminar Series, University of Wisconsin – Madison Wisconsin Institute of Discovery, 12/12/2011.
17. UW-Madison Robotics Laboratory: Medical Robotics Research Overview, University of Wisconsin – Madison Department of Surgery seminar, 02/25/2011.
18. UW-Madison Robotics Laboratory: Medical Robotics Research Overview, University of Wisconsin – Madison Cardio-thoracic Surgery seminar, 01/19/2011.
19. Robotic Catheters for Minimally Invasive Surgical Applications: Control and Sensing Challenges, University of Wisconsin – Madison Lindberg Lecture Series, Department of Mechanical Engineering, 10/02/2008.
20. Minimally-Invasive Robotic Catheters, University of Wisconsin – Madison Biomedical Engineering Seminar, 03/03/2008.
21. Robotic Catheters for Minimally Invasive Surgical Applications: Control and Sensing Challenges, University of Wisconsin – Madison Rheology Research Seminar (The Mohrs Lectures by Placon), 02/15/2008.

22. A New Actuation Approach For Human Friendly Robotics, University of Massachusetts – Amherst – Department of Computer Science Seminar Series, 11/05/2004.
23. Human-Friendly Robotics, Stanford University – Department of Computer Science, Advanced Robotics Guest Lecturer, 05/01/2003.