

PROPOSAL WHITE PAPER

Multidisciplinary Research Program
of the University Research Initiative
Fiscal Year 2010

ONR BAA 10-002

Topic: PROVABLY-SAFE PERCEPTION-BASED CONTROL
FOR AUTONOMOUS UAS OPERATIONS AROUND
COMPLEX UNSTRUCTURED TERRAIN

entitled

**Integrated sensing, dynamics and control for
bio-inspired agile flight**

Submitted by

Prof. Kristi A. Morgansen
University of Washington

Department of Aeronautics and Astronautics

Technical contact:

Prof. Kristi A. Morgansen:
Department of Aeronautics & Astronautics
Box 352400
Seattle, WA 98195-2400
Phone: (206) 616-5950

E-mail: morgansn@u.washington.edu

Co-Principal Investigators

Prof. John Baillieul (BU)
Prof. Calin Belta (BU)
Prof. Thomas Daniel (UW)
Prof. Tyson Hedrick (UNC-Chapel Hill)
Prof. Sean Humbert (U Maryland)
Prof. Thomas Kunz (BU)
Prof. Kristi A. Morgansen (UW)
Prof. Ioannis Ch. Paschalidis (BU)
Prof. Juris Vagners (UW)

Submitted to:

ATTN: Dr. Marc Steinberg
ATTN: ONR Code 03R
MURI '10
Office of Naval Research
875 N. Randolph St.
Suite W256A
Arlington, VA 22203-1768

Figure 1: Snazzy image here

1. Identification of the Research Issues

Current and future naval military scenarios are increasingly dependent on the use of autonomous vehicles and systems for reconnaissance, payload recovery and delivery, weapons, and interception of suspicious marine vehicles.

The approach of the work in this project will be to develop. . .

2. Proposed Technical Approaches

In order to achieve the development of the individual and group capabilities, several interconnected technologies, requiring novel integration of disciplines, must be developed. To this end, the proposed research will be organized around XXX interconnected themes. Years 1-3 of the project will focus on basic research issues with a transition to the development of a deployed prototype system during years 4 and 5.

KEY FEATURES

- agile flight (transient rather than steady state)
- landing and station keeping
- integrated sensing and actuation
- sensing and motion planning (which is not the same as the item above)
- biological networks and neural networks
- optimization
- provable methods

Testbeds

- UW: hawkmoths, high speed cameras, wind tunnel, Boeing quadrotors, 3D tracking methods (algorithms)
- BU: bats (high speed cameras?), quadrotor, cameras on notes
- UMD: quadrotors, etc, high speed cameras
- UNC: birds?

QUESTIONS

- should we arrange the following with biology separate from engineering, or with biology and engineering in each theme?
- 3D tracking of bats/insects/birds for modeling - capabilities/equipment in place?

2.1 Theme 1:

2.2 Theme 2:

2.3 Theme 3

2.4 Theme 4

2.6 Testbeds, experiments and prototype development

3. Potential Impact on DoD Capabilities

The research in this project will be informed by previous work supported under XXX programs (PI names) and by established collaborations between the investigators and DoD-funded work at ... With the expertise within the group and its collaborators, we believe the research will be successful not only in theoretical developments but also in direct translation to the field.

Existing DoD work:

- Baillieul: AFOSR MURI (dynamical systems/human cognition, PI)
- Belta: ONR MURI (BU PI), ARO (distributed control), ASFOSR YIP (coord control)
- Daniel:
- Hedrick:
- Humbert:
- Morgansen: AFOSR MURI (dynamical systems/human cognition, CoPI), ONR (Seaglid-ers)
- Paschalidis:
- Vagners: AFOSR MURI (dynamical systems/human cognition)

4. Potential Team and Management Plan

The research team will be comprised of YYY well known researchers from ZZZ major universities in the United States, together with their graduate students and post docs. While the team is located at a several number of sites, this group has a long-standing and successful history of collaboration and interaction. This existing history will be drawn on to ensure the success of the project using quarterly tele-conferences for the whole group, more frequent teleconferences for subgroups, working meetings at joint conferences, and yearly workshops in addition to the annual ONR contractor's meeting. The senior researchers are listed on the cover of the white paper and include: . References relevant to the proposed research may be found in the appended CVs of these investigators. The lead institution will be the University of Washington with P.I. K. Morgansen.

5. Summary of Estimated Costs

The proposed effort anticipates a budget of 1.5M per year. The institutional breakdown is University of Washington: \$AAA, BU: \$BBB, UMD: \$CCC, UNC: \$DDD. The University

of Washington budget includes project management, support for annual meetings, and costs of subcontracts. The budget includes support for graduate students, senior researchers and post-docs, and modest travel and equipment costs.

INVESTIGATOR CONTRIBUTION AREAS

John Baillieul (BU): models to navigate UAVs through densely packed obstacles at high speeds, papers on related conceptual ideas

robotics, the control of mechanical systems, and mathematical system theory. He has done research and written about (1) the connections between optimal control theory and what has recently been called “sub-Riemannian geometry,” (2) problems in the control of nonlinear systems modeled by homogeneous polynomial differential equations, (3) the control theory of rotating elastic systems, (4) motion planning and control of kinematically redundant manipulators, and (5) problems associated with anholonomy in planning motions for robots which have elastic joints and other components which store energy. Recently he has become interested in problems in information based control, networked control systems, and communication- constrained control of nonholonomic systems.

Calin Belta (BU): I will develop theoretical and computational frameworks that will allow for provably safe control of dynamical systems. I have the feeling that the kind of systems that we will deal with in this project will be hybrid and stochastic (e.g., will have continuous dynamics to model the flight dynamics, stochastic terms to capture the uncertainty, and discrete dynamics (automata) to capture qualitative knowledge, specifications given in high level language, discrete events, etc.). Then the question is how to design control strategies for such systems that are provably safe. We will use ideas from formal verification. We will abstract complex hybrid stochastic dynamics evolving in infinite spaces to finite probabilistic systems such as MDP and POMDP. We will develop control strategies for such systems by drawing inspiration from probabilistic model checking and temporal logic games. We have several preliminary results both for the abstraction and the control process, for both non-probabilistic and probabilistic systems.

Thomas Daniel (UW): bio-inspired sensori-motor systems and the melding of sensors and actuators. Most of my interests would focus on biological IMUs (halteres, antennae and even wings), special methods for encoding self motion, disambiguating multi-axis motion sensing. I also have a foot in propulsion dynamics with flexing wings. I think it would be particularly exciting to consider propulsors that provide both actuation and sensory information about their loading, Coriolis forces and much more.

Tyson Hedrick (UNC): My group has many years of experience in recording free-flight kinematics and behavior from birds, insects and bats using calibrated high-speed cameras. Most prior work in this area, both from my lab and elsewhere, has focused on laboratory or other controlled environment studies, e.g. a cockatoo navigating an indoor flight corridor or a hawkmoth tracking an actuated flower in a laboratory flight chamber. We are prepared to perform similar types of experiments as part of this project such as records of the trajectories of flying animals landing in unfamiliar circumstances or navigating an obstacle filled laboratory flight corridor. We are also beginning to pursue flight recordings from wild animals in natural settings including birds flying under a forest canopy. These sorts of recordings might be especially useful if the MURI revolves around control in fast forward flight, which is difficult to elicit in confined laboratory spaces.

Sean Humbert (UMD): Intersection of dynamics and control theory with the rapidly emerging area of bio-inspired sensing and locomotion. Recent efforts have focused on formalizing the control relevance of the spatial decompositions of optic flow performed within the insect visuomotor system, and have resulted in novel methodologies for visual stabiliza-

tion of autonomous guidance and navigational tasks.

Tom Kunz (BU): ecologist - bats bat flight behavior (10 yrs) thermal infrared imaging (to date for censusing) with CS for algorithms funding from AFOSR - high end thermal, high speed cameras, 1000x1000px NSF - collective behavior, bat motion in 3D ground based LIDAR to characterize 3D images in forests Q: how clutter affects movement of bats

My research largely focuses on how free-ranging mammals acquire and allocate energy and nutrients during reproduction. I am interested in patterns of parental investment and the energetic costs of pregnancy and lactation in temperate and tropical bats. A related area of interest is intraspecific and interspecific variation and energetics of postnatal growth in bats. We are trying to assess the ecosystems services of Brazilian free-tailed bats (*Tadarida brasiliensis*), a species that forms one of the largest aggregations of mammals known to mankind. These insectivorous species feed on a wide range of aerial insects, some of which are considered to be major agricultural pests, including corn earworms and cotton bollworms. In collaboration with Professors Margrit Betke, Stan Sclaroff, and Cutler Cleveland (Boston University), and Gary F. McCracken (University of Tennessee), we are using infrared thermal imaging to census bats as they emerge nightly from caves, NEXRAD II Doppler radar to assess landscape patterns of nightly dispersal, and economic modeling to assess the impact that this insectivorous species has on a major agroecosystem in Texas.

Kristi Morgansen (UW): My group has experience with bioinspired design and nonlinear control based on the biomechanics of locomotion with flapping fins. We will work on nonlinear control aspects of sensing and actuation in flexible wing flight using simplified models. We are also working on aircraft deconfliction algorithms and will work with the biologists to determine whether currently used engineering algorithms of obstacle avoidance and deconfliction match the data from biological flight.

Ioannis Ch. Paschalidis (BU): Decision theory, networking, optimization sensor networks supporting network infrastructure localization without GPS algorithms for navigation, planning, dynamic optimization robustness, **robust optimization** - optimization doesn't lead to robust solution

1) Localization, Movement detection, ranging, and tracking, using RF signals but also additional hardware modalities. The purpose would be to extend the utility of GPS in places where GPS is not available or accurate enough (due to the environment, e.g., indoors, very dense urban areas, or due to its cost).

2) Several navigation/exploration problems to be considered can be formulated as stochastic dynamic programming problems. Bellman's curse of dimensionality makes them intractable. I am interested in approximate DP approaches. One approach we have worked with falls into the so called class of actor-critic methods. In fact, the structure of the method has a nice behavioral interpretation.

3) Energy aware consensus/averaging. We have looked into consensus/averaging among energy-limited agents and have ways of optimizing the consensus/averaging protocol to minimize energy consumption.

4) Delay tolerant networking or harvesting sensor fields. In some instances there is no fixed/reliable communication infrastructure to connect isolated nodes (e.g., think of wireless energy-limited sensor nodes that are sparsely deployed and the network is not connected). Airborne robots can provide this connectivity by flying over these sensor fields (potentially deployed in hostile terrain) and collect the information they have acquired. We have devel-

oped some schemes to that end, optimizing the manner in which the airborne robots should visit the sensor fields (to optimize delays).

5) In uncertain/rapidly changing terrains agents need to solve optimization problems but in a robust manner to avoid the typical "fragility" of optimal solutions in the presence of uncertainty. Robust optimization techniques can come to the rescue ... Could be useful for safety, failure-proof operation of the airborne robots. There may be interesting connections to bats that are apparently well "optimized" fliers but do not appear "robust enough" to avoid wind turbines

Juris Vagners (UW): leveraging agile human pilot methods for this work mission planning, task allocation, collision recovery flight mechanics

application of unconventional control techniques, i.e., artificial neural networks, fuzzy logic and evolutionary programming, to control systems design. Most recently, his research has focused on autonomous and semi-autonomous Uninhabited Aerial Vehicles (UAVs). Also, cooperative path and mission planning for multiple UAVs, collaboration between UAVs and Unmanned Ground Vehicles (UGVs) and Unmanned Surface Vehicles (USVs), and human-in-the-loop control.

6. Curriculum Vitae of Key Investigators

JOHN BAILLIEUL

Boston University
Department of Mechanical Engineering
Department of Electrical and Computer Engineering
Boston, MA 02215

Tel.: (617) 353-9848
FAX: (617) 353-5866
e-mail: johnb@bu.edu
<http://people.bu.edu/johnb>

Current Positions

Professor of Mechanical Engineering (formerly AME, 1985 – present), Boston University;
Professor of Manufacturing Engineering (1988–2008; program terminated), Boston University;
Professor of Electrical and Computer Engineering (2001–present), Boston University.

Education

Ph.D. (1975), M.S. (1973), Harvard University;
M.M. (1969), University of Waterloo (CANADA);
Attended (1967-68) The Johns Hopkins University;
B.A. (*Magna Cum Laude* - Mathematics), (1967) University of Massachusetts.

Experience

9/75–6/79 Assistant Professor of Mathematics, Georgetown Univ.;
6/79–9/83 Consultant; Senior Technical Staff, Scientific Systems, Inc.
9/83–12/84 Vinton Hayes Visiting Scientist, Harvard University
9/91–12/91 Visiting Professor of Electrical Engineering, MIT
7/04 NICTA Visiting Researcher, Dept. of Electrical and Electronic Engineering, the University of Melbourne, Melbourne, AU
8/05 Visiting Research Professor, Department of Electrical & Computer Engineering, National University of Singapore
1/85–present Professor, College of Engineering, Boston University

Research

Interests

John Baillieul's research deals with mechanics and the control of mechanical and mechatronic systems. His PhD dissertation, completed at Harvard University under the direction of R.W. Brockett in 1975, was an early work dealing with connections between optimal control theory and what has recently been called "sub-Riemannian geometry." Much of his current research is devoted to applying the methods of dynamical systems theory and modern geometric non-linear control theory to problems of current technological interest. He is also interested in information-based control systems and the communications problems that arise in implementing computer control of complex physical systems. Baillieul has extensive experience in D.o.D. sponsored research and has been Boston University PI on three MURI grants.

Selected

Honors

IEEE Fellow, SIAM Fellow, IEEE Control Systems Society Distinguished Member Award (1994), IEEE Third Millennium Medal (2000).

Professional Activities

- Assoc. Ed. for Tech. Notes and Corresp., *IEEE Trans. on Aut. Control*, 1989-1992.
- Editorial Board of the *Int'l J. of Bifurcation and Chaos*, 1990-1994.
- Associate Editor *IEEE Robotics and Automation Society Newsletter*, 1990-1992.
- Editor in Chief, *IEEE Trans. on Aut. Control*, 1992 - 1998.
- Ed. Board, *Proceedings of the IEEE*, 1998—
- Ed. Board, *Wiley Encyclopedia of Electrical and Electronics Engineering*, J.G. Webster, Editor, 1998.
- Ed. Board, *Robotics and Computer Integrated Manufacturing*, Pergamon Press, 1999—
- Ed. Board, *Communications in Information and Systems*, 2000—
- IEEE Vice President for Publications Services and Products, 2007 - 2008

- Editor-in-Chief, *SICON-SIAM J. on Control and Optimization*, 2006—.

Graduate Theses Supervised

Masters: 9 completed; Doctoral: 7 completed, 4 in progress.

Selected

Invited

Lectures

Eminent Speaker Series of the Charles Brown Department of Electrical Engineering, University of Virginia: “The Evolving Applications of Control Theory to Devices, Networks and Life Itself,” Friday, Oct. 26th, 2007. Plenary Lecture: “Rethinking Control Engineering in a Networked World,” Keynote/Plenary Lecture, The First International Conference on Computer Science and Education, (ICCSE’ 2006), Xiamen, China, July 27, 2006.

Selected Publications

- “Control with Time-Varying Feedback Communication Constraints—The Case of Dimension Greater than One,” *Proceedings of the 2004 Asian Control Conference*, pp. 1906-1914, July 2004.
- “Data-rate Requirements for Nonlinear Feedback Control,” *Proceedings of NOLCOS 2004 - Symposium on Nonlinear Control Systems*, Stuttgart, September 1-3, 2004, Vol. 3, pp. 1277-1282.
- “Robust Quantization for Digital Finite Communication Bandwidth (DFCB) Control,” *IEEE Trans. on Automat. Contr.* Special Issue on Networked Control Systems, September, 2004, Vol. 49:9, pp. 1573-1584.
- “Robust and Efficient Quantization and Coding for Control of Multidimensional Linear Systems under Data Rate Constraints,” *International Journal of Robust and Nonlinear Control* Special Issue on Communicating-Agent Systems. Volume 17, Issue 10-11, pp. 898 - 920, Published Online: 20 Nov 2006 DOI: 10.1002/rnc.1142. (With Keyong Li)
- “Risk Sensitive Control of Complex Dynamical Systems,” in the *45-th IEEE Conference on Decision and Control*, San Diego, December 13-15, 2006.
- “Control and Communication Challenges in Networked Real-Time Systems,” *Proceedings of the IEEE*, 95:1, January, 2007, pp. 9-28 Digital Object Identifier 10.1109/JPROC.2006.887290 (with Panos Antsaklis)
- “Autonomous vehicle control for ascending/descending along a potential field with two applications, Accepted for the 2008 American Control Conference, Seattle, Washington, June 11-13, 2008, WeBI01.7, p. 678-683. (With D. Baranov)
- “Search Decisions for Teams of Automata, in Proceedings of the 47-th IEEE Conference on Decision and Control, Cancun, MX, December 9-11, 2009, Paper TuB15.4, pp. 1133-1138. (With D. Baronov)
- “Control Communication Complexity of Nonlinear Systems.” *Communications in Information and Systems*, Special Issue on the Legacy of Roger W. Brockett, Vol. 9, No. 1, 2009, pp. 103-140. (With W.S. Wong) Available for download at <http://people.bu.edu/johnb/CIS-9-1-A5-wong.pdf>

Synergistic Activities:

- NSF ITR Grant No. DMI-0330171, “Sensors and Sensor Networks: A Control and Optimization Science Base for Sensor Networks in Adverse and Stochastic Environments,” Grant period: Sept. 1, 2003 - September 30, 2009, Five year total (incl. subcontract to UMass, Amherst): \$2,487,459.
- “Behavioral Dynamics in the Cooperative Control of Mixed Human/Robotic Teams,” MURI Topic 16, FY 2007 ONR BAA 06-028 \$1.5M/year for a four university consortium (Boston Univ., Princeton, UCSB, Washington). Period of performance: May 1, 2007 - April 30, 2012.

Calin A. Belta

Mechanical Engineering, Systems Engineering, and Bioinformatics
Center for Information and Systems Engineering
Center for Biodynamics
Boston University
110 Cummington St., Boston, MA 02215
Tel: 617.353.9586, Fax: 617.353.5548, Email: cbelta@bu.edu
URL: <http://hyness.bu.edu/calin>

(i) Professional Preparation

| | | |
|--------------------------------|--|-----------------|
| Gh.Asachi Technical University | Automatic Control and Computer Science | B.S., M.S. 1995 |
| Gh.Asachi Technical University | Control | M.S. 1996 |
| Louisiana State University | Electrical Engineering | M.S. 1999 |
| University of Pennsylvania | Mechanical Engineering | M.S. 2001 |
| University of Pennsylvania | Mechanical Engineering | Ph.D. 2003 |

(ii) Appointments

2005 – Assistant Professor, Boston University
2003 – 2005 Assistant Professor, Drexel University
1999 – 2003 Graduate Research Fellow, University of Pennsylvania
1997 – 1999 Graduate Research Fellow, Louisiana State University
1995 – 1997 Jr. Assist. Prof. of Control and Computer Science, Gh.Asachi Technical University

(iii) Ten Related Publications (all available at <http://hyness.bu.edu/calin/>)

1. M. Lahijanian, C. Belta, and S. Andersson, A Probabilistic Approach for Control of a Stochastic System from LTL Specifications, IEEE Conference on Decision and Control (CDC), Shanghai, China, 2009 (in print)
2. M. Kloetzer and C. Belta, Automatic deployment of distributed teams of robots from temporal logic motion specifications, IEEE Transactions on Robotics, 2009 (in print)
3. M. Kloetzer and C. Belta, A fully automated framework for control of linear systems from temporal logic specifications, IEEE Transactions on Automatic Control, vol. 53, no. 1, pp. 287-297, 2008
4. C. Belta and L.C.G.J.M. Habets, Control of a class of nonlinear systems on rectangles, IEEE Transactions on Automatic Control, vol. 51, no. 11, pg. 1749 – 1759, 2006
5. M. Kloetzer and C. Belta, Dealing with non-determinism in symbolic control, 11th Int. Conf. on Hybrid Systems: Computation and Control, Lecture Notes in Computer Science, Springer, eds. M. Egerstedt and B. Mishra, vol. 4981, pp. 287-300, 2008
6. M. Kloetzer and C. Belta, Distributed implementations of global temporal logic motion specifications, IEEE Int. Conf. on Robotics and Automation (ICRA), Pasadena, CA, 2008
7. C. Belta, A. Bicchi, M. Egerstedt, E. Frazzoli, E. Klavins, and G. J. Pappas, Symbolic Planning and Control of Robot Motion, IEEE Robotics and Automation Magazine, Special issue: Grand Challenges of Robotics, vol. 14, no. 1, pp. 61–71, 2007
8. M. Kloetzer and C. Belta, Temporal Logic Planning and Control of Robotic Swarms by Hierarchical Abstractions, IEEE Transactions on Robotics, vol.23, no.2, pp. 320-331, 2007

9. C. Belta and V. Kumar, Abstraction and control for groups of robots, IEEE Transactions on Robotics, vol.20, no.5, pp. 865-875, 2004

10. C. Belta, V. Isler, and G. J. Pappas, Discrete abstractions for robot planning and control in polygonal environments, IEEE Transactions on Robotics, vol.21, no.5, pp.864-874, 2005

(iv) Synergistic Activities

Editorial activities: Associate Editor for the SIAM Journal on Control and Optimization (SICON), the IFAC Technical Committee on Discrete Event and Hybrid Systems, the Conference Editorial Board of the IEEE CSS, and the Conference Editorial Board of the IEEE RAS; Member of the Steering Committee for the IEEE RAS Technical Committee on Algorithms for Planning and Control of Robot Motion.

Conference PC: Int. Workshop on Hybrid Systems: Computation and Control (HSCC) 2009, 2008, 2007, 2006; Robotics: Science and Systems (RSS) 2005, Int. Conf. on Advanced Robotics (ICAR) 2007, 2005; IEEE/RSJ Int. Conf. on Intelligent Robots and Systems (IROS) 2007, 2006; Int. Conf. on Robot Communication and Coordination (ROBOCOMM) 2009, 2007; American Control Conf. (ACC) 2009, 2008, 2007; IEEE Int. Conference on Robotics and Automation (ICRA) 2007, 2006, 2005.

Organized workshops and invited sessions: Workshop on Hybrid Systems Biology at HSCC 2009, Invited Session on Analysis and Control of Biochemical Networks at CDC 2008, Invited Session on Symbolic Methods for Control of Mobile Robots at ICRA 2007, Workshop on Symbolic Approaches to Robot Planning and Control at RSS 2006.

Outreach: Judge for the US FIRST Robotics Competition, VEX Bridge Battle, and the Delaware Valley Young Inventors Competition. Advisor for the Upper Darby Robotics team at Upper Darby High School and the FIRST Robotics at the BU Academy.

(v) Collaborators & Other Affiliations

(a) Collaborators

Alur, Rajeev – Professor of Computer Science, University of Pennsylvania

Dang, Thao – Researcher, INRIA, France

Habets, Luc – Professor of Mathematics, Eindhoven University of Technology

Pappas, George – Professor of Electrical and Systems Engineering, University of Pennsylvania

Rubin, Harvey -- Professor of Medicine and Microbiology, University of Pennsylvania

(b) Graduate advisor

Vijay Kumar – Professor of Mechanical Engineering and Computer Science, University of Pennsylvania

(vi) Awards

AFOSR Young Investigator Award, 2008

NSF CAREER Award, 2005

Best Paper Award, Int. Conf. Systems Biology, Heidelberg, Germany, 2004

Best Paper Award Finalist, ASME DETC, Montreal, Canada, 2002

Best Student Paper Award Finalist, ICRA, Seoul, Korea, 2001

Fulbright Study Award, 1997

THOMAS L. DANIEL

Department of Biology
University of Washington
Seattle, WA 98195

Voice: (206) 543-1659; Lab: (206) 543-7335; FAX (206) 543-3041

Web page: <http://faculty.washington.edu/danielt>

Professional Preparation

| | | |
|-------------------------|-----------------|------|
| University of Wisconsin | B.S. | 1976 |
| University of Wisconsin | M.S. | 1978 |
| Duke University | Ph.D. (Zoology) | 1982 |

Appointments

| | |
|--------------|--|
| 2002-2008 | Chair, Department of Biology, University of Washington |
| 2003-present | Adjunct Professor, Department of Bioengineering, University of Washington |
| 1999-2002 | Associate Professor, Department of Zoology, University of Washington |
| 1997-present | Professor, Neurobiology and Behavior Faculty, University of Washington |
| 1992-present | Professor, Department of Biology (prior Zoology), University of Washington |
| 1988-1992 | Associate Professor, Department of Zoology, University of Washington |
| 1984-1988 | Assistant Professor, Department of Zoology, University of Washington |
| 1982-1984 | Myron A. Bantrell Postdoctoral Fellow, Engineering Sciences, Caltech |

Awards, Honors, and Boards:

| | |
|------------|---|
| 1989 | University of Washington Distinguished Teaching Award |
| 1991-1997 | Panel member, Physiological Processes, National Science Foundation |
| 1991 | University of Washington Special Merit Award for Outstanding Teaching |
| 1993-1999 | Director of the NSF Graduate Training Grant in Mathematical Biology, UW |
| 1996-2001 | MacArthur Fellow, John D. and Catharine T. MacArthur Foundation |
| 1998- | University of Washington Komen Professorship in Biology |
| 1998-2002 | Board of Directors, University of Washington Foundation |
| 1998-2004 | Editorial Board, J. Comparative and Integrative Biology |
| 2000-2001 | The Alan T. Waterman Award Committee, National Science Foundation |
| 2001- 2003 | Editorial Board, J. Theoretical Biology |
| 2002- | University of Washington Distinguished Graduate Mentor Award |
| 2005- | Board of Directors, P.G. Allen, Experience Learning Community (ELC) |
| 2006- | Board of Directors, Allen Institute of Brain Science (AIBS) |
| 2006- | Editorial Board, <i>Biology Letters</i> , Royal Society for Sciences |
| 2006-2009 | Scientific Advisory Board, Center for Cell Types and Circuits, AIBS. |

Publications Relevant to Proposal

Fox, J.L., Fairhall, A. and Daniel, T.L. (2009). Encoding properties of haltere neurons permit detection of Coriolis forces. (in review) *Proc. Natl. Acad. Sci.*

Daniel, T.L., Dieudonne, A., Fox, J, Myhrvold, C., Sane, S.P., and Wark, B. (2009) Inertial guidance systems in insects: from the neurobiology to the structural mechanics of biological gyroscopes. *J. Navigation. In press.*

- Mountcastle, A. and Daniel, T.L. (2008) Aerodynamic and functional consequences of wing compliance. *Experiments in Fluids* 0723-4864
- Fox, J.L. and Daniel, T.L. (2008). A neural basis for gyroscopic encoding in the halteres of *Holorusia*. *Journal of Comparative Physiology A* 194: 887-897.
- Tanner, B.C.W, Regnier, M., and Daniel, T.L.(2008). A spatially-explicit model of muscle contraction explains a relationship[between activation phase, power, and ATP utilization in insect flight. *J. Exp. Biol.* 211:180-186.
- Tanner, B.C.W.T., Daniel, T.L., and Regnier, M. (2007). Sarcomere lattice geometry influences cooperative myosin binding in muscle. *PLoS Computational Biology* Vol. 3, No. 7, e115 doi:10.1371/journal.pcbi.0030115
- Sane, S.P., Dieudonne, A., Willis, M.A. and Daniel, T.L. (2007) Antennal mechanical sensors mediate flight control in Lepidoptera. *Science*. **315**:771-772.
- Nishikawa, K, Biewener, A.A., Aerts, P., Ahn, A.N., Chiel, H.J., Daley, M.A., Daniel, T.L., Full, R.J., Hale, M.E., Hedrick, T.L., Koditschek, D.E., Lappin, A.K., Nichols, T.R., Quinn, R.D., Ritzman, R.E., Satterlie, R.A., Szymik, B. (2007) Neuromechanics: an integrative approach for understanding motor control. *Integrative and Comparative Biology*. **47**: 16-54
- Hedrick, T.L. and Daniel, T.L (2006) Flight control in the hawkmoth *Manduca sexta*: the inverse problem of hovering. *J. Exp. Biol.* **209**:3114-3140.
- Daniel, T.L. and Combes, S.A. (2002). Flexing wings and fins: bending by inertial or fluid dynamic forces? *Int. Comparative Biol.* **42**:1044-1049.
- Sprayberry, J. and Daniel, T.L. (2007). Flower tracking in hawkmoths: behavior and energetics. *J. Exp. Biol.* 210:37-45.
- Combes, S. and Daniel, T.L. (2005). Flexural stiffness in insect wings: effects of wing venation and stiffness distribution on passive bending. *American Entomologist*. 42-45.
- Tu, M.S. and Daniel, T.L. (2004). Cardiac like behavior in insect flight muscle. *J. Exp. Biol.* **207**,2455-2464.
- Combes, S.A. and Daniel, T.L. (2003). Flexural stiffness in insect wings. I. Scaling and the influence of wing venation. *J. Exp. Biol.* **206**: 2979-2987.

Current collaborators on existing, recent, or pending grants (outside of UW).

Michael Dickinson, California Institute of Technology (ONR)
 John Hildebrand, University of Arizona (DARPA)
 Jeffery Lang, , Massachusetts Institute of Technology (DARPA)
 Rick Levine, University of Arizona (DARPA)
 Martin Schmit, , Massachusetts Institute of Technology (DARPA)
 Joel Voldman, Massachusetts Institute of Technology (DARPA)
 Mark Willis, Case Western Reserve, (ONR)

Recent graduate students or postdocs (past five years)

Stacey Combes, Assistant Professor, Harvard University (graduate student and postdoc)
 Alexandre Dieudonne, Postdoc, HHMI Janelia Farms (graduate student)
 Mark Frye, Assistant Professor, UCLA, (graduate student)
 Erica Goldman, Science Writer, University of Maryland (graduate student)
 Jordanna Henry, Assistant Professor, Muhlenberg College (graduate student)

Biographical Sketch: Tyson L. Hedrick

Professional Preparation

- 1993 – 1997: Brown University, Rhode Island B.S. in Biology, Honors Honors thesis: The Biomechanics of Head-Butting in Bighorn Sheep
- 1999 – 2004: Harvard University, Massachusetts Ph.D. (2004) in Biology Dissertation: Aerodynamics, biomechanics and neuromuscular control of avian flight
- 2004 – 2006: University of Washington, Seattle NSF Postdoctoral Research Fellowship in Biological Informatics Control theory applications to the flight of the hawkmoth, *Manduca sexta*

Appointments

July 2007 - current: Assistant Professor, Department of Biology, University of North Carolina (Chapel Hill)

Publications

(i) publications related to the proposal

- Hedrick, T. L., Cheng, B. and Deng, X. (2009). Wingbeat time and the scaling of passive, rotational damping in flapping flight. *Science* 324, 252-255.
- Hedrick, T. L. (2008). Software techniques for two- and three-dimensional kinematic measurements of biological and biomimetic systems. *Bioinspiration & Biomimetics* 3, 034001.
- Hedrick, T. L. and Biewener, A. A. (2007). Low speed maneuvering flight of the rose-breasted cockatoo (*Eolophus roseicapillus*) I. Kinematic and neuromuscular control of turning. *J. Exp. Biol.* 210, 1897-1911.
- Hedrick, T. L., Usherwood, J. R. and Biewener, A. A. (2007). Low speed maneuvering flight of the rose-breasted cockatoo (*Eolophus roseicapillus*) II. Inertial and aerodynamic reorientation. *J. Exp. Biol.* 210, 1912-1924.
- Hedrick, T. L. and Daniel, T. L. (2006). Flight control in the hawk moth *Manduca sexta*: the inverse problem of hovering. *J. Exp. Biol.* 209, 3114-3130.

(ii) other significant publications

- Tobalske, B. W., Warrick, D. R., Clark, C. J., Powers, D. R., Hedrick, T. L., Hyder, G. A. and Biewener, A. A. (2007). Three-dimensional kinematics of hummingbird flight. *J. Exp. Biol.* 210, 2368-2382.
- Hedrick, T. L., Usherwood, J. R. and Biewener, A. A. (2004). Wing inertia and whole body acceleration: an analysis of instantaneous aerodynamic force production in cockatiels (*Nymphicus hollandicus*) flying across a range of speeds. *J. Exp. Biol.* 207, 1689-1702.
- Tobalske, B. W., Hedrick, T. L., Dial, K. P. and Biewener, A. A. (2003). Comparative power curves in bird flight. *Nature* 421, 363-366.
- Hedrick, T. L., Tobalske, B. W. and Biewener, A. A. (2003). How cockatiels (*Nymphicus hollandicus*) modulate pectoralis power output across flight speeds. *J. Exp. Biol.* 206, 1363-1378.
- Hedrick, T. L., Tobalske, B. W. and Biewener, A. A. (2002). Estimates of circulation and gait change based on a three-dimensional kinematic analysis of flight in cockatiels (*Nymphicus hollandicus*) and ringed turtle-doves (*Streptopelia risoria*). *J. Exp. Biol.* 205, 1389-1409.

Synergistic activities

Design, implementation and distribution of MATLAB based software for calibrating cameras, manually and automatically digitizing kinematic markers in video files and reconstructing their coordinates in 3D. Freely available at <http://www.unc.edu/~thedrick/> and used by researchers at many institutions in the US and UK in the fields of organismal biology and engineering.

Member of the steering committee for the NSF-funded RCN: A Research Coordination Network for X-ray Motion Analysis

Making available high quality slow motion video recordings of birds in flight for use in teaching and other presentations
– <http://www.unc.edu/~thedrick/movies.html>

Providing organizational assistance for the 2008 Southeast regional meeting of the SICB division of comparative biomechanics, hosted at Clemson University, and acting as host and primary organizer for the 2009 meeting held at UNC Chapel Hill

Collaborators and co-editors

Andrew Biewener (Harvard U.), Kenny Breuer (Brown U.), Jian Chen (Brown U.), Bo Cheng (Purdue U.), Chris Clark (U. of California, Berkeley), Thomas Daniel (U. of Washington), Xinyan Deng (Purdue U.), Nickolay Hristov (Winston-Salem State University), Gabriel Hyder (U. of Portland), Jose Iriate-Diaz (Brown U.), Joel Kingsolver (U. of North Carolina, Chapel Hill), Mykhaylo Kostandov (Brown U.), David Laidlaw (Brown U.), Rajat Mittal (The Johns Hopkins U.), Donald Powers (George Fox U.), Daniel Riskin (Brown U.), Sharon Swartz (Brown U.), Bret Tobalske (U. of Montana, Missoula), James Usherwood (Royal Veterinary College), Doug Warrick (Oregon State U.), David Willis (Brown U.)

Ph.D. advisor:

Andrew Biewener, Harvard University

Postdoctoral advisor:

Thomas Daniel, University of Washington

Thesis advisor or postdoctoral sponsor:

Jeremy Greeter, University of North Carolina at Chapel Hill

Professional Preparation:

| | | |
|------------------------------------|------------------------|-------------------------------|
| University of California, Davis | Mechanical Engineering | Bachelor of Science, 1997 |
| California Institute of Technology | Mechanical Engineering | Master of Science, 1999 |
| California Institute of Technology | Mechanical Engineering | Doctor of Philosophy, 2001-05 |

Appointments:

| | |
|--|--------------|
| Assistant Professor, Aerospace Engineering, University of Maryland at College Park | 2005-Present |
| <i>Joint appointment in:</i> Bio-Engineering Graduate Program | 2006-Present |
| Program Manager, Space & Strategic Programs, Pratt & Whitney Space Propulsion | 2000-2002 |
| Senior Design Engineer, Pratt & Whitney Space Propulsion | 1999-2000 |
| Visiting Researcher, United Technologies Research Center, Hartford, CT | 1998 |

Relevant Publications:

1. Humbert JS, Hyslop AM, “Bio-Inspired Visuomotor Convergence”, *IEEE Transactions on Robotics*, (in press)
2. Conroy JK, Gremillion G, Raganathan BN, Humbert JS, “Implementation of Wide-Field Integration of Optic Flow for Autonomous Quadrotor Navigation”, *Autonomous Robots*, Vol. 27, No. 3, pp.189-198, 2009
3. Hyslop AM, Humbert JS, “Autonomous Navigation in 3-D Urban Environments Using Wide-Field Integration of Optic Flow”, *AIAA Journal of Guidance, Control, and Dynamics*, (in press)
4. Faruque I, Humbert JS, “Dipteran Insect Flight Dynamics: Part 1: Longitudinal Motions About Hover”, *Journal of Theoretical Biology*, (accepted)
5. Grauer J, Conroy JK, Hubbard JE Jr, and Humbert JS, “System Identification of a Miniature Helicopter”, *AIAA Journal of Aircraft*, Vol. 46, No. 4, pp. 1260-1269, 2009

Other Selected Publications:

6. Conroy JK, Humbert JS, and Pines DJ, “System Identification of a Rotary Wing Micro Air Vehicle”, *Journal of the American Helicopter Society*, in press
7. Humbert JS, Murray RM, and Dickinson MH, “Pitch-Altitude Control and Terrain Following Based on Bio-Inspired Visuomotor Convergence”, *AIAA Conference on Guidance, Navigation and Control*, San Francisco, CA, 2005. *Winner of best paper award*
8. Humbert JS, Murray RM, and Dickinson MH, “A Control-Oriented Analysis of Bio-Inspired Visuomotor Convergence”, *44th IEEE Conference on Decision and Control*, Seville, Spain, 2005
9. Humbert JS, and Frye MA, “Extracting Behaviorally Relevant Retinal Image Motion Cues via Wide-Field Integration”, *American Control Conference*, Minneapolis, MN, 2006
10. Reiser MB, Humbert JS, Dunlop MJ, Del Vecchio D, Murray RM, and Dickinson MH, “Vision as a Compensatory Mechanism for Disturbance Rejection in Upwind Flight”, *American Control Conference*, Boston, MA, 2004. *Winner of best student paper competition*

Honors and Awards:

1. AIAA Hal Andrews Young Scientist/Engineer of the Year Award, 2009
2. AIAA Outstanding Professor of the Year, Department of Aerospace Engineering, UMCP, 2007
3. AIAA Outstanding Mentor Award, Department of Aerospace Engineering, UMCP, 2006
4. Best Paper Award, AIAA Conference on Guidance, Navigation, and Control, 2005
5. Best Student Paper Award, American Control Conference (ACC), 2004
6. Best Poster Prize, International Workshop on Insect Sensors and Robotics, 2004
7. Departmental Citation, Mechanical Engineering, UCD, 1997

Collaborators:

Dr. Holger Krapp, Bioengineering, Imperial College, London

Dr. Patrick Shoemaker, Tanner Research, Inc.

Dr. Ron Fearing, Electrical and Computer Engineering, University of CA, Berkeley

Dr. Mark Frye, Physiological Sciences, University of California, Los Angeles

Dr. Richard Murray, Control and Dynamical Systems, California Institute of Technology

Dr. Michael Dickinson, Bioengineering, California Institute of Technology

Dr. Wei Shyy, Aerospace Engineering, University of Michigan

Dr. Pamela Abshire, Electrical and Computer Engineering, University of Maryland

Dr. Jim Paduano, Aurora Flight Sciences, Inc.

Dr. David O'Carroll, Biology, University of Adelaide

Dr. Geoffrey Barrows, Centeye

Graduate Advisors:

Dr. Richard Murray, Control and Dynamical Systems, California Institute of Technology

Dr. Michael Dickinson, Bioengineering, California Institute of Technology

BIOSKETCH

Thomas H. Kunz

a. Professional Preparation

| | | | |
|--------------------------------|-------------------------|-------|------|
| University of Central Missouri | Biology | B.S. | 1961 |
| University of Central Missouri | Education | M.S. | 1962 |
| Drake University | Biology | M.S. | 1968 |
| University of Kansas | Systematics and Ecology | Ph.D. | 1971 |

b. Appointments

| | |
|---|--------------|
| Director, Center for Ecology and Conservation Biology | 1996-present |
| Professor, Department of Biology, Boston University | 1984-present |
| Chairman, Department of Biology, Boston University | 1985-1990 |
| Associate Professor, Department of Biology, Boston University | 1977-1984 |
| Assistant Professor, Department of Biology, Boston University | 1971-1977 |

c. Publications

(i) Five publications most closely related to proposed research

- Kunz, T.H.**, E.B. Arnett, W.P. Erickson, G.D. Johnson, R.P. Larkin, M.D. Strickland, R.W. Thresher, and M.D. Tuttle. 2007. Ecological impacts of wind energy development on bats: questions, hypotheses, and research needs. *Frontiers in Ecology and Environment*, 5: 315-324.
- Kunz T.H.**, S.A. Gauthreaux, Jr., N.I. Hristov, J.W. Horn, G. Jones, E.K.V. Kalko, R.P. Larkin, G.F. McCracken, S.W. Swartz, R.B. Srygley, R. Dudley, J.K. Westbrook, and M. Wikelski. 2008. Aeroecology: probing and modelling the aerosphere. *Integrative and Comparative Biology*, 48: 1-11.
- Kunz, T.H.**, E.B. Arnett, B. M. Cooper, W.P. Erickson, R.P. Larkin, T. Mabee, M.L. Morrison, M.D. Strickland, and J.M. Szewczak. 2007. Assessing impacts of wind energy development on nocturnally active birds and bats: a guidance document. *Journal of Wildlife Management*, 71: 2449-2486.
- Horn, J.W., and **T.H. Kunz**. 2008. Analyzing NEXRAD Doppler radar images to assess nightly dispersal patterns and population trends in Brazilian free-tailed bats (*Tadarida brasiliensis*). *Integrative and Comparative Biology*, 48: 24-39.
- Hristov, N.I., M. Betke, and **T.H. Kunz**. 2008. Applications of thermal infrared imaging for research in aeroecology. *Integrative and Comparative Biology*, 48: 50-59

(ii) Five other significant publications

- Betke, M., D.E. Hirsh, N.C. Makris, G.F. McCracken, M. Procopio, N.I. Hristov, S. Teng, A. Bagchi, J.D. Reichard, J.W. Horn, S. Crampton, C.J. Cleveland, and **T.H. Kunz**. 2008. Thermal imaging reveals significantly smaller Brazilian free-tailed bat colonies than previously estimated. *Journal of Mammalogy*, 89: 18-24.
- Riskin, D.K., J.W. Bahlmam, T.Y. Hubel, J.M. Ratcliffe, **T.H. Kunz**, and S.M. Swartz. 2009. Bats go head under heels: the biomechanics of landing on a ceiling. *Journal of Experimental Biology*, 212:945-953.
- Hallam, T.G., A. Raghavan, H.J. Kolli, D.T. Dimitrov, P. Federico, H. Qui, G.F. McCracken, M. Betke, J. Westbrook, K. Kennard, and **T.H. Kunz**. 2009. Dense and sparse aggregations in complex motion: video coupled with simulation modeling. *Ecological Complexity*, doi:10.1016/j.ecocom.2009.05.012.
- Robinson, W.D., M.S. Bowlin, I. Bisson, J. Shamoun-Baranes, K. Thorup, R. Diehl, **T.H. Kunz**, S. Mabey, and D.W. Winkler. 2009. Integrating concepts and technologies at the frontiers of bird migration. *Frontiers of Ecology and the Environment*, doi:10.1890/080179.
- Wu, Z., N.I. Hristov, T.L. Hedrick, **T.H. Kunz**, and M. Betke. 2009. Tracking a large number of objects

from multiple views. International Conference on Computer Vision, 29 September-2 October, Kyoto, Japan.

d. Synergistic Activities

- (i) *Undergraduate Student Research Mentor*: For the past 38 years, **Kunz** has advised and supervised research projects of over 60 undergraduate students, 25 of which have led to publications in peer-reviewed journals. During this period, he has been the PI on several NSF-funded undergraduate research programs (URP 10 years and REU 12 years).
- (ii) *Tropical Ecology Program in Ecuador*: **Kunz** was instrumental in developing a semester-long tropical ecology program in Ecuador designed for undergraduate students. This program provides unique educational and research opportunities for qualified undergraduate students from Boston University and students who attend other colleges and universities (www.bu.edu/cecb).
- (iii) *Public and Professional Lectures*: **Kunz** is regularly invited to give public lectures to local school groups (K-12), conservation organizations, and museums about his research on bats. He also is regularly invited to give lectures at colleges and universities and at national and international meetings on topics related to his research.
- (iv) *Professional Societies*: **Kunz** is an active member of several professional societies and is the recent past president of the American Society of Mammalogists (2000-2002). Kunz also serves on the scientific advisory boards of several non-government organizations, including the Lube Bat Conservancy (USA), Bat Conservation International (USA), and IUCN—World Conservation Union (Gland, Switzerland).

e. Collaborators and Other Affiliations

- (i) *Collaborators*: Manfred Ayasse (University of Ulm, Germany); Margrit Betke (Boston University), Hari Bhat (Institute of Virology, India); Cutler Cleveland (Boston University); Brock Fenton (University of Western Ontario, Canada); Jeff Frank (Indigo Systems, Inc., Santa Barbara); Gareth Jones (University of Bristol, UK); Sid Gauthreaux (Clemson University); Thomas Hallam (University of Tennessee); Elisabeth Kalko (University of Ulm, Germany); Jeffrey Kelly (University of Oklahoma); Ron Larkin (University of Illinois); Thomas Little, (Boston University), Gurpathy Marimuthu (Kamaraj Madurai University, India); Gary McCracken (University of Tennessee); Stuart Parsons (University of Auckland, New Zealand); John Westbrook (USDA); Eric Widmaier (Boston University); Akbar Zubaid (Universiti Kebangsaan Malaysia); Christian Voigt (Institute of Zoo and Wildlife Research, Germany).
- (ii) *Graduate and Postdoctoral Advisors*
Rodney A. Rogers, Emeritus (M.A.), Drake University
J. Knox Jones, Jr.--deceased (Ph.D.), University of Kansas
- (iii) *Graduate Students and Post-doctoral Scholars Sponsored (past 5 years)*
Graduate Students (40 total): Polly Campbell, University of New Mexico (2000-2005); Chris Richardson, University of Wisconsin (1998-2006); Lizabeth Southworth, Saginaw Valley State University (1996-2004); Gloriana Chaverri, Universidad Nacional, Costa Rica (2001-2006); Benjamin Rinehart, University of Colorado (1997-2007); Jason Horn, Cornell (2000-2007); Mariana Munoz-Romo, Universidad Simon Bolivar (2004-2008), Louise Allen, Michigan State University (2003-2008); Susan Murray, University of Massachusetts (1999-present); Pablo Jarrin, Pontificia Universidad Catolica del Ecuador (2003-present), Jonathan Reichard, Cornell University (2003-present); Marianne Moore, Evergreen College (2005-present), Nate Fuller, Shippensburg University (2009-present); Aryn Wilder, Colorado State University (2009-present).
Post-doctoral Scholars (15 total): DeeAnn Reeder, University of California, Davis (2001-2004); Tigga Kingston, Boston University (2001-2005); Nikolay Hristov, Wake Forest University (2004-2007); Robert Hodgkison, University of Aberdeen (2004-2008), Christopher Richardson, Boston University (2006-present); Winifred Frick, Oregon State University (2008-present).

Kristi A. Morgansen

Associate Professor, Department of Aeronautics and Astronautics
University of Washington, Box 352400, Seattle, WA 98195-2400
phone: (206) 616-5950; fax: (206) 543-0217
email: morgansen@aa.washington.edu

PROFESSIONAL PREPARATION:

Boston University, Boston, MA, Mechanical Engineering, **B. S.**, 1993.
Boston University, Boston, MA, Mechanical Engineering, **M. S.**, 1994.
Harvard University, Cambridge, MA, Applied Mathematics, **Sc. M.**, 1996.
Harvard University, Cambridge, MA, Engineering Science, **Ph.D.**, 1999.

APPOINTMENTS:

2009-present Associate Professor, Department of Aeronautics and Astronautics, University of Washington, Seattle, WA.
2002-2009 Assistant Professor, Department of Aeronautics and Astronautics, University of Washington, Seattle, WA.
2001-2002 Senior Research Fellow, Control and Dynamical Systems/Mechanical Engineering, California Institute of Technology, Pasadena, CA.
1999-2001 Postdoctoral Scholar, Control and Dynamical Systems/Mechanical Engineering, California Institute of Technology, Pasadena, CA.

HONORS & AWARDS:

Senior Member of the IEEE (2006)
NSF CAREER Award (2003-2009)
Clare Boothe Luce Assistant Professor of Engineering (2002-2007)

FIVE PUBLICATIONS MOST CLOSELY RELATED TO PROJECT:

- [1] R. Pagliari, S. Kirti, K. A. Morgansen, T. Javidi and A. Scaglione, "A simple and scalable algorithm for alignment in broadcast networks," *IEEE Journal on Selected Areas in Communication*, (accepted).
- [2] E. Lalish and K. A. Morgansen, "Decentralized reactive collision avoidance for multivehicle systems," in *Proceedings of the IEEE Conference on Decision and Control*, December 2008.
- [3] D. J. Klein, P. Lee, K. A. Morgansen, and T. Javidi, "Integration of communication and control using discrete time Kuramoto models for multivehicle coordination over broadcast networks," *IEEE Journal on Selected Areas in Communication*, 26(4):695-705, May 2008.
- [4] D. J. Klein, P. K. Bettale, B. I. Triplett, and K. A. Morgansen, "Autonomous underwater multivehicle control with limited communication: Theory and experiment," in *Proceedings of the IFAC Workshop on Navigation, Guidance and Control of Underwater Vehicles*, April 2008.
- [5] K. A. Morgansen, B. I. Triplett, and D. J. Klein, "Geometric methods for modeling and control of free-swimming fin-actuated underwater vehicles," *IEEE Transactions on Robotics*, 23(6):1184-1199, Dec. 2007.

FIVE OTHER PUBLICATIONS:

- [6] L. Vu and K. A. Morgansen, “Stability of feedback switched linear systems with state and switching delays,” *IEEE Transactions on Automatic Control*, in review.
- [7] B. I. Triplett, D. J. Klein and K. A. Morgansen, “Cooperative estimation for coordinated target tracking in a cluttered environment,” *ACM/Springer Mobile Networks and Applications Journal (MONET)*, (invited—special issue), 14(3):336-349, June 2009.
- [8] D. J. Klein, C. Matlack, and K. A. Morgansen, “Cooperative target tracking using oscillator models in 3D,” in *Proc. of the IEEE American Control Conference*, 2007.
- [9] D. J. Klein and K.A. Morgansen, “Controlled collective motion for trajectory tracking,” in *Proc. of the IEEE American Control Conference*, 2006.
- [10] B. I. Triplett, D. J. Klein, and K. A. Morgansen, “Discrete time Kuramoto models with delay,” in *Lecture Notes in Control and Information Sciences*, Springer, 2005.

SYNERGISTIC ACTIVITIES

- 1999- Associate Editor, IEEE Control System Society Conference Editorial Board.
- 2006 Created a biorobotics project module for ENGR 100, an engineering project course for non-majors.
- 2007-2008 Local Arrangements Chair 2008 American Control Conference.
- 2007- Chair, Aeronautics & Astronautics Undergraduate Committee.
- 2009 Lab development and access for high school and college students with disabilities.

COLLABORATORS (past 48 months)

John Baillieul (Boston Univ.), Francesco Bullo (UCSB), David Castanon (Boston Univ.), Jonathan D. Cohen (Princeton), Prof. Daniel Grunbaum (UW), Philip Holmes (Princeton), Tara Javidi (UCSD), Naomi Leonard (Princeton), Julia Parrish (UW), Deborah Prentice (Princeton), Anna Scaglione (Cornell), Takashi Tsukamaki (Boeing Phantomworks), Juris Vagners (UW), Craig Woolsey (VA Tech).

GRADUATE AND POST-GRADUATE ADVISORS AND ADVISEES:

Graduate and post-graduate advisors to Kristi A. Morgansen:

Ph.D.: Prof. Roger Brockett, Harvard University;

Postgraduate: Prof. Joel Burdick, California Institute of Technology and Prof. Richard Murray, California Institute of Technology

Graduate students advised:

Past: Patrick Bettale (MS EE), JaeDong Hwang (MS AA), Daniel J. Klein (PhD AA), Kyle Krogh (MS AA), Brian Massey (MS AA), Kudah Mushambi (MS AA), Randall Svac (MS AA), Benjamin I. Triplett (PhD AA).

Current: Emmett Lalish (PhD AA), Andrew Melander (MS AA), Nathan Powel (PhD AA), Caleb Woodruff (PhD AA).

Postdoctoral students advised:

Past: Dr. Anawat Pongpunwattana.

Current: Dr. Linh Vu, Dr. Christopher Lum.

IOANNIS CH. PASCHALIDIS

Boston University
Department of Electrical and Computer Engineering,
Division of Systems Engineering,
and Center for Information and Systems Engineering (CISE),
Boston, MA 02215

Tel.: (617) 353-0434
FAX: (617) 353-6440
e-mail: yannisp@bu.edu
<http://ionia.bu.edu/>

Title Professor, Electrical, Computer, & Systems Eng. (9/09–present), Boston Univ.
Co-Director (9/04–present), Center for Information and Systems Eng., Boston University.
Academic Director (11/04–present), The Sensor Network Consortium – an industry consortium with 14 industry members.

Education Ph.D. (1996), S.M. (1993), both in EECS, Massachusetts Institute of Technology;
Diploma in ECE (1991) National Technical University of Athens, Greece.

Appointments

1/00–8/09 Associate Professor; College of Engineering, Boston Univ. ;
9/03–12/03 Visiting Scholar, Columbia University Business School.
1/03–6/03 Visiting Scholar, Laboratory for Information and Decision Systems, MIT.
9/96–8/09 Assistant Professor, College of Engineering, Boston Univ. ;
9/00–12/01 Principal Scientist, Cogentrix Inc.
6/96–8/96 Post-Doctoral Associate, Laboratory for Information and Decision Systems, MIT.
9/91–6/96 Research Assistant, Teaching Assistant, Dept. of Elec. Eng. & Comp. Sc., MIT.
1/95 Technical Consultant, AT&T Bell Labs, Murray Hill, NJ.

Research Interests Systems and control, networking, applied probability, optimization, operations research, computational biology, and bioinformatics. Specifics topics of interest: Communication and sensor networks; Anomaly detection; Protein docking; Large deviations.

Selected Honors

- Invited Participant, *Workshop on Mathematics of Molecular and Cellular Biology, Protein Folding*, Institute for Mathematics and Its Applications (IMA), January 14-18.
- First prize, *3rd Critical Assessment PRedicted Interaction (CAPRI) Meeting*, April 20-21, 2007, Toronto, Canada, for presented poster publication (with Y. Shen, P. Vakili, and S. Vajda).
- Invited Participant, *2002 U.S. Frontiers of Engineering Symposium*, National Academy of Engineering (annual symposium organized by the NAE that brings together 100 of the nation's outstanding young engineers –ages 30-45– from industry, academia, and government).
- NSF CAREER Award (CISE Directorate, Networking Research), 2000.
- Plenary Speaker, 1998 and 2002 LIDS Student Conference, MIT.
- Second Prize, *INFORMS 1997 George E. Nicholson* paper competition.
- Elected Full Member of Sigma Xi, 1996, (MIT Chapter).
- Graduated ranking 1st, 1991, ECE Dept., National Technical Univ. of Athens, Greece.
- Seven times recipient of awards from the *National Scholarship Foundation of Greece* and the *Technical Chamber of Greece*.

Ten Selected Publications

(Summary: 3 book chapters, 81 refereed papers, 38 abstracts in conferences, 66 invited lectures, 12 theses supervised.)

[ICP1] “On Energy Optimized Averaging in Wireless Sensor Networks” (with B. Li), *Proceedings of the 48th IEEE Conference on Decision and Control*, December 2009, Shanghai, China.

- [ICP2] “An Actor-Critic Method Using Least Squares Temporal Difference Learning with an Application to Warehouse Management” (with K. Li, R. Moazzez-Estanjini), *Proceedings of the 48th IEEE Conference on Decision and Control*, December 2009, Shanghai, China.
- [ICP3] “A Distributed Actor-Critic Algorithm and Applications to Mobile Sensor Network Coordination Problems” (with P. Pennesi), *IEEE Transactions on Automatic Control*, in print.
- [ICP4] “Robust and Distributed Stochastic Localization in Sensor Networks: Theory and Experimental Results” (with Dong Guo), *ACM Transactions on Sensor Networks*, Vol. 5 (2009), No. 4 (November).
- [ICP5] “Spatio-Temporal Network Anomaly Detection by Assessing Deviations of Empirical Measures” (with G. Smaragdakis), *IEEE/ACM Transactions on Networking*, Vol. 17 (2009), No. 3 (June), pages 685-697.
- [ICP6] “Protein docking by the underestimation of free energy funnels in the space of encounter complexes” (with Y. Shen, P. Vakili, and S. Vajda), *PLoS Computational Biology*, Vol. 4 (2008), No. 10 (October).
- [ICP7] “Asymptotically Optimal Transmission Policies for Large-Scale Low-Power Wireless Sensor Networks” (with W. Lai and D. Starobinski), *IEEE/ACM Transactions on Networking*, Vol. 15 (2007), No. 1, pages 105-118.
- [ICP8] “Statistical Location Detection with Sensor Networks” (with S. Ray and W. Lai), *IEEE Transactions on Information Theory, Joint special issue with IEEE/ACM Transactions on Networking on Networking and Information Theory*, Vol. 52 (2006), No. 6, pages 2670-2683.
- [ICP9] “Robust Linear Optimization: On the benefits of distributional information and applications in inventory control” (with Seong-Cheol Kang), *Proceedings of the 44th IEEE Conference on Decision and Control*, pages 4416-4421, December 2005, Seville, Spain.
- [ICP10] “Pricing in Multiservice Loss Networks: Static Pricing, Asymptotic Optimality, and Demand Substitution Effects” (with Y. Liu), *IEEE/ACM Transactions on Networking*, Vol. 10 (2002), No. 3, pages 425-438.

Professional Activities

- Associate Editor: *IEEE Trans. Automatic Control* (1/06-present), *Operations Research Letters* (2/02-present), *Automatica* (8/02-12/07).
- Technical Committees: Chair, *Tech. Committee Networks & Communication Sys.*, IEEE Control Sys. Soc., (1/06-present); Member, Intern. Federation Automatic Control (IFAC) Tech. Committee Stochastic Sys.
- Program committees: Program committees for the *American Control Conf.*, *IEEE INFOCOM*, *IEEE Conf. Decision & Control*, and *INFORMS Applied Probability Conf.*
- Organizing committees: Co-Organizer, Workshop on “Challenges/Opportunities in Distributed Sensor Nets”, *Los Alamos National Laboratory*, March 2006; Organizer of two *Symposia* on Sensor Networks at Boston U., 11/2005 and 4/2004; Organizing Committees *46th (2007) and 43rd (2004) IEEE Conf. on Decision & Control*; Organizing committee, *1998 Information Theory Symposium*.

Relevant Experience

Co-Director of the BU Center for Information & Systems Eng. with 30 affiliated faculty and more than \$ 14 M in active sponsored projects. Academic director of the Sensor Network Consortium – an industry consortium with 14 industry members including the leading providers of sensor network platforms for commercial and military use (Ember, Honeywell, Millennial Net, MITRE, Siemens, Sun, Textron); Co-PI of ARO MURI on Networked Control Systems (BU, Harvard, Maryland, Illinois); PI of collaborative NSF ITR with Univ. of Illinois, MIT, and Yale on “Diagnosis and Assessment of Faults, Misbehavior and Threats in Distributed Systems and Networks”; PI of NIH project on protein docking; PI or Co-PI for about \$ 15.6 M since 1997.

Ph.D. and Postdoctoral Advisors

Prof. D. Bertsimas, MIT and Prof. J. Tsitsiklis, MIT.

JURIS VAGNERS

Professor Emeritus, Box 352400, Department of Aeronautics and Astronautics
University of Washington, Seattle, WA 98195
office phone: (206) 616-3590; office fax: (206) 543-0217; email: vagners@u.washington.edu

PROFESSIONAL PREPARATION:

University of Washington, Seattle, WA, Aeronautical Engineering, **BSAA**, 1961.
Stanford University, Palo Alto, CA, Aeronautics and Astronautics, **MSAA**, 1963.
Stanford University, Palo Alto, CA, Aeronautical and Astronautical Sciences, **PhD**, 1967.

APPOINTMENTS:

2002-present Professor Emeritus, Aeronautics and Astronautics, University of Washington, Seattle, WA.
1994 – 2002 Professor, Aeronautics and Astronautics, University of Washington, Seattle, WA.
1982 – 2002 Professor, Applied Mathematics, University of Washington, Seattle, WA.
1994 – 2002 Adjunct Professor, Electrical Engineering, University of Washington, Seattle, WA.
1973 – 1980 Associate Professor, Aeronautics and Astronautics, University of Washington, Seattle, WA.
1969 – 1973 Assistant Professor, Aeronautics and Astronautics, University of Washington, Seattle, WA.
1967 – 1969 Acting Assistant Professor, Aeronautics and Astronautics, University of Washington, Seattle, WA.

INDUSTRIAL EMPLOYMENT

1961 – 1965 Lockheed Missiles and Space Company, Sunnyvale, CA

CONSULTING

Mathematical Sciences Northwest, Inc., Bellevue, WA Mathematical modeling, systems analysis.
Boeing Computer Services, Inc., Seattle, WA Optimization theory and applications, estimation, systems analysis, avionics algorithm design.
Sundstrand Data Control, Inc., Redmond, WA Instrument testing and design.
Boeing Military Airplanes, Seattle, WA. Control systems design, navigation filter design, flight test data analysis, numerical methods development.
Insitu, Inc. Bingen, WA. UAV guidance, navigation and control.

HONORS AND AWARDS

UW College of Engineering Outstanding Faculty Award, 1997
Academic Engineer of the Year, Puget Sound Engineering Council, 1997
Professor of the Year, Aeronautics and Astronautics, 1995, 2000

RESEARCH INTERESTS

Application of artificial neural networks, fuzzy logic and evolutionary computation to control systems design; guidance, navigation and control of (semi) autonomous systems; human/automaton interaction dynamics; mission management of (semi) autonomous systems

PUBLICATIONS MOST CLOSELY RELATED TO PROJECT:

1. T. McGeer and J. Vagners, "Historic crossing: an unmanned aircraft's Atlantic flight". GPS World 10(2): 24-30, February 1999.
2. T. McGeer, and J. Vagners, "Wide-scale use of long-range miniature Aerosondes over the world's oceans", Proc. AUVSI 26th Annual Symposium, Association for Unmanned Vehicle Systems International, Baltimore, Md, July, 1999

3. J. Vagners, T. McGeer, and L. Newcombe, "Quantitative Risk Management as a Regulatory Approach to Civil UAVs", International Workshop on UAV Certification, Paris, France, June, 1999
4. T. McGeer, J. Vagners, and G. Holland. "The Aerosonde: opportunities for miniature robotic aircraft following the 1998 Atlantic Crossing". 4th Annual Airborne Remote Sensing Conference and Exhibition/21st Canadian Symposium on Remote Sensing, Ottawa, Ontario, 21-24 June 1999
5. B. Capozzi, and J. Vagners, "Navigating Annoying Environments Through Evolution", 40th IEEE Conference on Decision and Control, Orlando, Florida, December 4-7, 2001,
6. B. Capozzi, and J. Vagners. "Evolving (Semi) Autonomous Vehicles", AIAA 2001 Guidance, Navigation and Control Conf. Montreal, Canada, Aug. 2001
7. A. Pongpunwattana, R. Rysdyk, J. Vagners, and D. Rathbun, "Market-based Co-evolution Planning for Multiple Autonomous Vehicles", 2nd AIAA Unmanned Systems Conf. San Diego, CA Sept 2003
8. D. Jia, and J. Vagners, "Parallel Evolutionary Algorithms for UAV Path Planning", AIAA 3rd "Unmanned Unlimited Technical Conference, Chicago, IL September 20 -23, 2004,
9. J.C. Rubio, J. Vagners, and R. Rysdyk, "Adaptive Path Planning for Autonomous UAV Oceanic Search Missions", AIAA 3rd "Unmanned Unlimited" Technical Conference, Chicago, IL September 20 -23, 2004
10. R.T. Rysdyk, C.W. Lum, and J. Vagners, "Autonomous Orbit Coordination for Two Unmanned Aerial Vehicles" *Proceedings of the AIAA Guidance, Navigation, and Control Conference*, August 2005
11. C.W. Lum and J. Vagners, "A Modular Algorithm for Exhaustive Map Searching Using Occupancy Based Maps" *Proceedings of the AIAA Infotech@Aerospace Conference*, April 2009
12. C.W. Lum, R.T. Rysdyk, and J. Vagners, "A Search Algorithm for Teams of Heterogeneous Agents with Coverage Guarantees" *To appear in the AIAA Journal of Aerospace Computing, Information, and Communication*
13. C.W. Lum, R.T. Rysdyk, and J. Vagners, "Rapid Verification and Validation of Strategic Autonomous Algorithms Using Human-in-the-Loop Architectures" *Submitted to the AIAA Journal of Aircraft*
14. C.W. Lum, J. Vagners, J. S. Jang, and J. Vian, "Partitioned Searching and Deconfliction: Analysis and Flight Test", Submitted to the 2010 AIAA Infotech@Aerospace Conference

CURRENT FUNDING RELEVANT TO THE PROPOSED PROJECT

"Behavioral Dynamics in the Cooperative Control of Mixed Human/robotic Teams", Air Force Office of Scientific Research 2007 MURI Topic #16, joint with Boston University, Princeton, UC Santa Barbara, 2007 – 2012

"Validation of Algorithms for Semi-Autonomous Operation of Collaborating UAVs in the Boeing Self-aware Autonomous Swarms Integration Laboratory", The Boeing Company, 2009

"Autonomous Launch, Recovery and Turn-Around Systems for Small UAVs", ONR STTR subcontract from AeroVél, 2009 -2010

SELECTED WORKSHOPS

DARPA Mixed Initiative Control of Automa teams (MICA) Variable Initiative Workshop, University of Washington, Seattle, WA. March 27 – 28, 2002

AFOSR Workshop on Future Directions in Control, Arlington, VA, April 26 – 27, 2002

AFOSR Workshop on UAV Testbeds and Simulation, August 12, 2004

DARPA ISAT Study Group on Embedded Humans, Woods Hole, MA. August 22 – 26, 2005

National Academies of Science Decadal Survey of Civil Aeronautics, Panel D, Dynamics, Navigation, Control and Avionics, Washington, DC, November 14, 2005