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Green Robotics, Automation, and Machine Intelligence; a new Engineering Course in Sustainable Design

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This paper describes a course developed as part of a new engineering program in Sustainable Design at a United States Liberal Arts college in Pennsylvania. This program involves all faculty of the Engineering & Physics department, and is a mix of environmental engineering and environmental design including both high-tech-green, and global environmental engineering & design. In addition to common courses for all engineering majors, the program requires courses in Drawing, Population & Global Issues, Green Architectural Engineering, Hydrology, Thermodynamics, Environmental Engineering, Environmental Site Engineering & Design, Sustainable Resource Engineering & Design, and Green Robotics, Automation, and Machine Intelligence -- the course described in this paper. This course is also required for Industrial Engineering Management Majors, Computer Engineering Majors, and Cognitive Science Minors. The course description includes "Cutting-edge innovations in robotics, automation, and machine intelligence that result in the most environmentally-friendly and humanity-sensitive use of technology and resources to manufacture products or aid humans." This includes various forms of machine intelligence, and mobile-robot and robotic-arm theory, applications, simulations, real-time control, and path-planning. Sustainability and green-related course topics include green manufacturing, biomimicry, environmental & space exploration & mapping, hazardous waste clean-up, smart-house design, active solar design, solar harvesting, wind turbines, automated agriculture, intelligent rapid transit and automobiles, and intelligent energy distribution, generation, and load-shedding. Ethical issues include restricting robot autonomy Some course content is derived from a Ph.D. engineering course in "Advanced Robotics with Application to Space Exploration" taught by the author at the University of Trento in Italy; a course that included lectures on designing an unmanned autonomous vehicle, and an unmanned underwater vehicle, for exploring the surface and ocean of Europa, one of the moons of Jupiter believed to possibly contain life in its sub-surface ocean. Related NASA and European Space Agency research is included. An internationally-competing autonomous robot built by the author's students is discussed; this robot has been entered three times into international competition and won an award for its communication protocol. The robot includes vision, GPS, and laser range finders; and has implemented various global & local path-planning methodologies for navigation. Most recently the robot is being retooled for environmental sampling, and plans are underway to deploy smaller robots for land, air, and water. A concurrent environmental map-building simulation is also planned, and has in the past been implemented on smaller robots in the lab. The present large robot is planned to interact with small drones collecting real-time sensory data to relay back to an environmental map-building simulation.

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1. Introduction

ERG/CS434 "Green Robotics, Automation, and Machine Intelligence" is taught at Elizabethtown College, a US Liberal Arts College in Pennsylvania. The course is required for the ABET-accredited BS Computer Engineering and BS Engineering (with Electrical, Mechanical, and Sustainable Design concentrations); and the BS Industrial Engineering Management and Cognitive Science Minor. The only prerequisites are courses in Computer Programming and Calculus.

1.1 Evolution of the Course

This course represents 20 years of related research and courses taught by the author at Elizabethtown College, Purdue University, and the University of Trento in Italy; plus additional research at IBM and A. I. Dupont Children's hospital. Some course content is from a Ph.D. engineering course in "Advanced Robotics with Application to Space Exploration" taught by the author at the University of Trento in 2009, including lectures on designing an unmanned autonomous vehicle, and an unmanned underwater vehicle, for exploring the surface and sub-surface ocean of Europa, a moon of Jupiter believed to possibly contain life. NASA and European Space Agency research is included. The course was taught at the University of Trento Engineering facility shown in Figure 1 which includes many research laboratories for large international robotics projects in manufacturing and space exploration. The course included lectures as outlined in Table 1.

Fig. 1 University of Trento Engineering.

Table 1 Ph.D. course in “Advanced Robotics with Application to Space Exploration” taught by the author at the Univ. of Trento, Italy.

LECTURES	READINGS
“OUR SOLAR SYSTEM” PPT PDF Terrestrial planets and moons	
“ROVERS IN SPACE” PPT PDF **1971** Lunar Rover (LRV) **1996** Mars Pathfinder *Sojourner* **2004** Mars Rovers *Spirit & Opportunity* **2011** *Mars Science Lab* **2016** Mars *ExoMars*	[3, 34, 35] [3, 4] [3]
“EUROPA” PPT PDF **1977** *Voyager 1 & 2* **1989** *Galileo* **2020** *Europa Jupiter System Mission* **2040 Europa Rover** (course project)	[4, 38] [4, 8] [2] [6, 8, 29]
“**ROVER MECHANICS**” PPT PDF Gravity effects, Manned vs. unmanned, Biological inspirations, Mobility, Suspension systems, Wheels and traction, Maneuverability, stability, and controllability	[1, 11, 33, 34, 35]
“DELIVERY SYSTEMS” PPT PDF Launch, landing, deployment, Shielding and hardening for heat, cold, radiation, and vibration	[3, 4, 9, 28]
“POWER” PPT PDF Electrical power demand, generation, and storage	[3]
“ARM DESIGN” PPT PDF Manned vs. unmanned tasks, instrument deployment vs. dexterous manipulation, Redundant and Hyper-redundant manipulators, Psuedo-inverse velocity-control **PATH-PLANNING**, Attractive poles, Repelling-fields, Creative use of null-space, Heuristic search, DOF minimization, *“**C**onsumption **Of A**vailable **R**edundancy (COAR),”* Rapid prototyping	[5, 14, 15]
“SENSORS & NAVIGATION” PPT PDF **PATH-PLANNING**, Dead reckoning, Celestial navigation, Mapping, Positioning, Steering, Sensors, Tele-operation, Remote communication, Local and global path-planning, Obstacle avoidance, Systems integration, Autonomy	[1, 3, 11, 12, 22, 18, 31, 32, 33, 36, 37]
“UAV’s, UUV’s, SWARMS” PPT PDF Unmanned Aerial Vehicles (UAV’s); Unmanned Underwater Vehicles (UUV’s) Networked swarms	[30]
“COMPUTING” PPT PDF Simulations, real-time control , Embedded systems, Microcontrollers, Microprocessors, PC’s, Workstations, Supercomputers, Quality control through *“Controlled Randomness”*	[17, 19, 25, *26*, 27, 28, 37]
“MACHINE INTELLIGENCE” PPT PDF Symbolic AI vs. connectionist architectures, Biologically-inspired vs. behavioral / mathematically-inspired neural networks, Neurocomputer design, Autonomy	[10, 13, 16]

This course also included an optional project for environmental exploration and mapping of Europa, which has become part of the course in “Green Robotics, Automation, and Machine Intelligence” at Elizabethtown College - and closely relates to the evolution of autonomous robots developed at the college.

2009 University of Trento Course Project Options

(A) Any project relating to the content of this course, and approved by your PhD advisor *OR*

(B) Conceptual Design of a Europa Rover. The mission objective is to explore the ocean under the ice of Europa. Assume your launch is scheduled for 2040.

Assume the ***Europa Jupiter System Mission*** [2] scheduled for launch in 2020 discovers patches of ice less than 200 meters thick created by localized sub-surface thermal anomalies; or assume a mission concurrent to yours (but designed by others) has created craters on Europa’s surface that have frozen over with approximately 200 meters of ice.

YOUR ROVER MUST BE ABLE TO:

1) Navigate the flat icy surface of Europa. Assume land mobility is required even though the main objective is exploring the ocean below.

2) Drill or melt through at least 200 meters of ice.

3) When water is reached, either act as a sole Unmanned Underwater Vehicle’s (UUV), or deploy 100 networked UUV’s (a “Swarm”); each 10 cm long, and each communicating with each other and the rover.

4) Communicate with a base station that is also communicating with several orbiters, and earth. The base station is running a concurrent simulation to the rover’s real-time code and is building an environmental-map simulation of the region of Europa being explored. The simulation should communicate back to the rover, and then to the UUV’s to help with exploration and preservation of the rover and the swarm.

5) Control a hyper-redundant manipulator attached to the rover to aid with exploration, digging, and/or deployment of small UUV’s.

6) Withstand the extreme cold (-143C), (-225F) of Europa [9]

7) Power everything by an energy source other than the sun since incident solar radiation reaching Europa is minimal. Assume the launch vehicle and delivery system are designed by others. Begin your rover’s trek on the surface by assuming a successful orbiter and base station have been deployed; you may assume your rover is delivered to the surface by a different method (and location) than how the base station was deployed. When estimating vehicle weight and maximum payload, consider that Europa’s gravity is only 13.5% of Earth’s.

Facts on Europa [8]:

- Discovered Jan 7, 1610 by Galileo Galilei
- Smallest of the four Galilean moons of Jupiter
- 6th largest satellite in our solar system
- Slightly smaller than our Moon
- Smoothest object in our solar system
- A mostly flat surface with nothing exceeding 1 km in height
- Surface is about 5 times brighter than our Moon’s
- Two types of terrains on icy crust: Mottled, brown or gray surface of mainly small hills; and large smooth plains crisscrossed with a large number of cracks
- Cracks similar to that of the ice at the Arctic Ocean on Earth
- There are not many craters on Europa – indicating a young age for the surface. The ones that exist are large
- Inner core suspected to be iron-sulfur similar to that of Io
- A tenuous atmosphere of oxygen has been detected
- As of 2009, most of the scientific community agreed that there is almost certainly a liquid ocean beneath the icy surface of Europa, and that the potential for microbial life exists [29], [38].
- Figure 2 is a NASA Galileo spacecraft image of Europa’s surface

Figure 2. Image of the surface of Europa's moon Jupiter taken from the 1989 NASA Galileo spacecraft shows 10km circles and cracks from the relatively warm liquid ocean beneath (heated by large tidal forces created by Jupiter) penetrating ice surface, then freezing.

- Europa Data:

Diameter (km):	3,138
Mass (kg):	4.8e22 kg
Mass (Earth = 1)	0.0083021
Surface Gravity (Earth = 1):	0.135
Mean Distance from Jupiter (km):	670,900
Mean Distance From Jupiter (Rj):	9.5
Mean Distance from Sun (AU):	5.203
Orbital period (days):	3.551181
Rotational period (days):	3.551181
Density (gm/cm³)	3.01
Orbit Eccentricity:	0.009
Orbit Inclination (degrees):	0.470
Orbit Speed (km/sec):	13.74
Escape velocity (km/sec):	2.02
Visual Albedo:	0.64
Surface Composition:	Water Ice

2. Environmental Explorations and Mapping on Campus

EGR/CS434 Green Robotics, Automation, and Machine Intelligence includes a required semester design project where students choose a topic from two main subject areas: (1) Green Automation, Manufacturing, and Smart-homes (discussed in next section); or (2) Conceptual design of two rovers – one as described above for the exploration of Europa, and the another using a modified version of the college's "Wunderbots" shown in Figure 3, and a new design of our "Aquabot" shown in Figure 4, to explore and map the environment in and around the campus lake also shown in Figure 4. Path planning may be accomplished using virtual "Attractors" and other techniques previously developed by the author [14, 15, 19, 20, 21] as illustrated in Figure 5. The two designs are required to be done simultaneously, with a final paper and presentation comparing and contrasting the decisions made for each design. Teams of three or four students are formed with as much diversity of knowledge as possible.

Figure 3. Some of the eight versions of Elizabethtown College's "Wunderbot"

Figure 4. Elizabethtown Aquabot (2004), and the College Lake

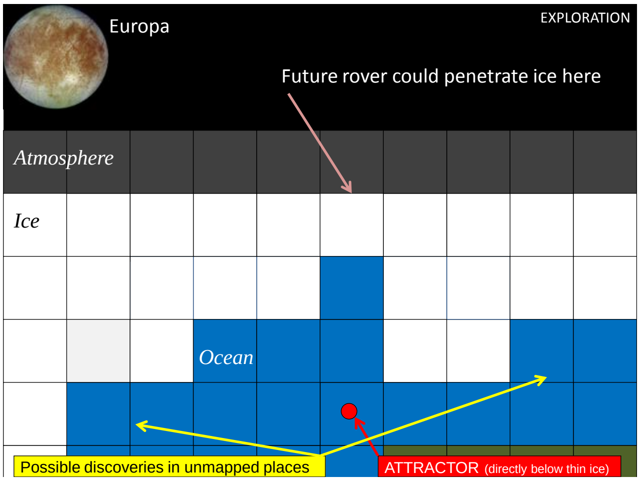

Figure 5. Proposed path-planning methodology for exploring unmapped oceans and lakes

3. Green Automation, Manufacturing, and Smart-homes

In EGR/CS434, students may choose this semester project as an alternate to the rover project described above. This project is more related to Industrial Engineering or Architecture. For this project, green topics such as green manufacturing and smart-house design may be chosen. One example is the hydroponic gardens shown in Figure 7 which were first made in 2010 by the student shown (Sean Flanagan); then later built by Sean on a larger scale or the Phoenix Contact company in a residential home; then again created by Sean for the Elizabethtown College Robotics and Machine Intelligence Lab as part of another course (EGR/CS333 "Digital Circuits & Computer Interfacing") as shown in Figure 7. This figure shows one of the two hydroponic tents in the lab.

Figure 7. Hydroponic garden automation in the Elizabethtown College Robotics & Machine Intelligence Lab.

Phoenix Contact Programmable Logic Controllers ("nano-LC") available for automation projects in the course are shown in Figure 8.

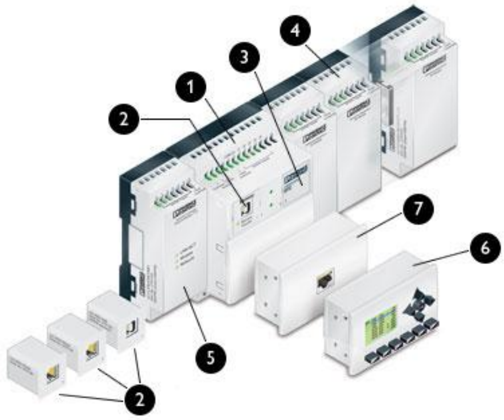

Figure 8. Phoenix Contact Programmable Logic Controller ("nano-LC") used for automation designs

4. Machine Intelligence

Although topics such as Expert Systems, Symbolic AI, and Neural Networks are each complex enough to consume an entire course or two, these topics are woven throughout EGR/CS434 by first teaching basic concepts, then focusing on selected applications. However, reading materials, handouts, and brief rigorous theoretical lectures supplement the course -- and students are allowed to pick from a number of questions on exams. Advanced topics such as multi-variable chain-rule proofs for deriving gradient decent neural network learning, and deriving the Jacobian Matrix of partial derivatives to define the mapping between Cartesian space and the joint-angle-space of a robotic arm's kinematics are discussed; with the anticipation that some students will select other questions to answer on exams. Two neurocomputers designed by the author [10,13,23,24] are discussed, including the VLSI chip shown in Figure 9. VLSI systems are being investigated in 2013/2014 to be incorporated into another course, EGR/CS433 "Advanced Computer Engineering" in 2014; sustainability-related projects from that course will be used as case-studies to enhance the Machine Intelligence content of EGR/CS434 "Green Robotics, Automation, and Machine Intelligence."

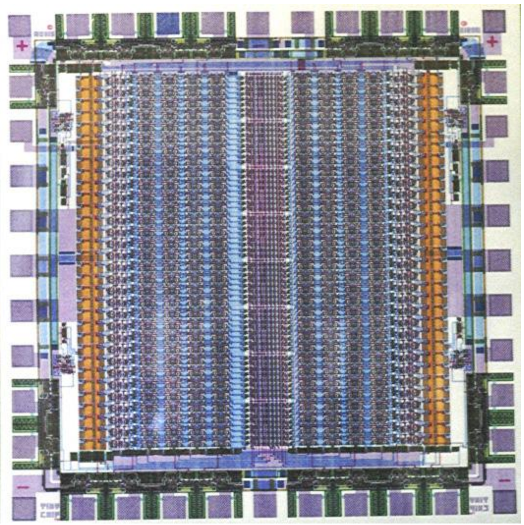

Figure 9. Artificial Dendritic Tree VLSI Neurocomputer Chip by author (1992)

5. Course Outline

I. International green trends
    A. United States
    B. Japan
    C. European Union
II. Green standards (ISO, LEED, governmental)
III. Green manufacturing
IV. Introduction to mobile robots
    Path-planning, obstacle avoidance, real-time sensor fusion, vision, laser range finders, ultrasonic sensors, GPS navigation, digital compass, motor types, wheel configurations
V. Introduction to robotic arms
    Kinematic controls schemes (position, velocity, acceleration), path-planning, obstacle avoidance, hyper-redundant arms, constrained workspaces, rehab robotics, assistive surgery, industrial arms
VI. Introduction to symbolic AI
    Predicate calculus, heuristics, knowledge representations, programming, Expert Systems
VII. Introduction to connectionist machines
    "Bottom-up" *biological* brain models vs. "Top-down" *psychological* models, Mathematical theory
VIII. Concurrent Simulation and real-time code
IX. Biomimicry
    A. Animal biomechanics, senses, control systems
    B. Plants
X. Applications
    A. Space exploration (NASA & ESA)
    B. Environmental mapping
        Wetlands, terrain, buildings, planets
    C. Environmental probes
    D. Hazardous waste clean-up
    E. Search & rescue
    F. Smart-house design
    G. Active solar
    H. Solar harvesting
    I. Wind turbines
    J. Automated agriculture
    K. Intelligent rapid transit systems
    L. Intelligent cars (including solar)
    M. Intelligent energy distribution
    N. Intelligent energy generation
    O. Energy load-shedding
XI. Merging forms of machine intelligence
    IBM "Watson" vs. IBM "Deep Blue"
XII. Ethical Issues
    A. Replacing humans vs. aiding humans
    B. Artificial humanoids
        Workers, entertainers, companions
    C. Designing autonomy
        Safety of life and property
    D. Autonomous military drones

6. Conclusions

ERG/CS434 "Green Robotics, Automation, and Machine Intelligence" is a required course for the Elizabethtown College ABET-accredited BS in Computer Engineering, the Sustainable Design concentration of the ABET accredited BS in Engineering, the BS in Industrial Engineering Management, and the Cognitive Science Minor. Therefore the course needs to serve a diverse technical audience All these disciplines fall under the umbrella the college's Strategic Plan which includes becoming more Green and sustainable in everything we do. The only prerequisites for the course are Computer Programming (Java or C), and Calculus I. Some sustainability and green-related course topics include green manufacturing. biomimicry, environmental & space exploration & mapping, hazardous waste clean-up, smart-house design, active solar design, solar harvesting, wind turbines, automated agriculture, intelligent rapid transit and automobiles, and intelligent energy distribution, generation, and load-shedding. Ethical issues include restricting robot autonomy [47]. Some course content is from a Ph.D. engineering course in "Advanced Robotics with Application to Space Exploration" taught by the author at the University of Trento in Italy; a course that includes lectures on designing an unmanned autonomous vehicle for environmental exploration and mapping of the surface and sub-surface ocean of Europa, one of the moons of Jupiter believed to possibly contain life. Reference to related NASA and European Space Agency research is included. An internationally competing autonomous rover built by the author's students is also discussed; this robot has been entered three times into international competition and won an award for its communication protocol. The robot includes vision, GPS, laser range finders, and global & local path-planning methodologies for navigation. Most recently the robot is being retooled for environmental sampling, and plans are underway to deploy smaller robots and probes for land, air, and water. A concurrent environmental map-building simulation is also planned, and has in the past been implemented on smaller robots in the lab [17,19]. The present large robot is planned to interact with small drones collecting real-time sensory data to relay back to an environmental map-building simulation. This course covers a significant amount of content in one semester, so much care is needed in covering all subjects in a way that students don't feel overwhelmed. All course subjects are taught through a "Green lense" - with a sustainability ethos permeating all lectures and student objectives.

REFERENCES

1. R. Siegwart and I. Nourbakhsh, *Autonomous mobile robots*, Massachusetts Institute of Technology, 2004.
2. K.. Clark, A. Stankov, R. Pappalardo, M. Blanc, R. Greeley, J.P.Lebreton , *Europa Jupiter System Mission; A Joint Endeavour by ESA and NASA*, NASA Report, January 16, 2009.
3. Anthony H. Young, *Lunar and planetary rovers: the wheels of Apollo and the quest for mars*, Springer; 1 edition, August 1, 2006.
4. Paolo Ulivi and David M. Harland, *Robotic exploration of the solar system: part II: hiatus and renewal, 1983-1996*, Praxis; 1 edition, November 25, 2008.
5. S. . B. Niku, *Introduction to Robotics: Analysis, Systems, Applications*, Prentice Hall, July 30, 2001.
6. R. Greenberg, *Unmasking Europa: The search for life on jupiter's ocean moon*, Springer; 1 edition, August 19, 2008.
7. R. Audouze (Editor), G. Israel (Editor), *The cambridge atlas of astronomy*, Cambridge University Press; 3 edition, November 28, 1994.
8. Website: *Europa, a Continuing Story of Discovery* [http://www2.jpl.nasa.gov/galileo/europa/].

9. Website: *JPL Photojournal* [http://photojournal.jpl.nasa.gov/catalog/PIA01144].
10. Wunderlich, J.T. (2013). Two single-chip neurocomputer designs; one bottom-up, one top-down. *(journal paper draft)*
11. Painter J. and Wunderlich, J.T. (2008). Wunderbot IV: autonomous robot for international competition. In *Proceedings of the 12th World Multi-Conference on Systemics, Cybernetics and Informatics: WMSCI 2008, Orlando, FL*: (pp. 62-67).
12. Coleman, D. and Wunderlich, J.T. (2008). O^3: an optimal and opportunistic path planner (with obstacle avoidance) using voronoi polygons. In *Proceedings of IEEE the 10th international Workshop on Advanced Motion Control, Trento, Italy.* vol. 1, (pp. 371-376). IEEE Press.
13. Wunderlich, J.T. (2004). Top-down vs. bottom-up neurocomputer design. In *Intelligent Engineering Systems through Artificial Neural Networks, Proceedings of ANNIE 2004 International Conference, St. Louis, MO.* H. Dagli (Ed.): Vol. 14. (pp. 855-866). ASME Press. [*"Novel Smart Engineering System Design Award, 2nd runner-up best paper"* from over 300 submissions],
14. Wunderlich, J.T. (2004). Simulating a robotic arm in a box: redundant kinematics, path planning, and rapid-prototyping for enclosed spaces. In *Transactions of the Society for Modeling and Simulation International*: Vol. 80. (pp. 301-316). San Diego, CA: Sage Publications.
15. Wunderlich, J.T. (2004). Design of a welding arm for unibody automobile assembly. In *Proceedings of IMG04 Intelligent Manipulation and Grasping International Conference, Genova, Italy,* R. Molfino (Ed.): (pp. 117-122). Genova, Italy: Grafica KC s.n.c Press.
16. Wunderlich, J.T. (2003). Defining the limits of machine intelligence. In *Proceedings of IEEE SoutheastCon, Ocho Rios, Jamaica,* [CD-ROM]. IEEE Press.
17. Campos, D. and Wunderlich, J. T. (2002). Development of an interactive simulation with real-time robots for search and rescue. In *Proceedings of IEEE/ASME International conference on Flexible Automation, Hiroshima, Japan*: (session U-007). ASME Press.
18. Lister, M. and Wunderlich, J. T. (2002). Digital communications for a mobile robot. In *Proceedings of IEEE SoutheastCon,* Columbia, SC, [CD-ROM]. IEEE Press.
19. Wunderlich, J.T. (2001). Simulation vs. real-time control; with applications to robotics and neural networks. In *Proceedings of 2001 ASEE Annual Conference & Exposition, Albuquerque, NM*: (session 2793), [CD-ROM]. ASEE Publications.
20. Wunderlich, J.T. and Boncelet, C.G (1996). Local optimization of redundant manipulator kinematics within constrained workspaces. In *Proceedings of IEEE Int'l Conference on Robotics and Automation*, Minneapolis, MN: Vol. (1). (pp. 127-132). IEEE Press.
21. Wunderlich, J.T. (1996). Optimal kinematic design of redundant and hyper-redundant manipulators for constrained workspaces. *Ph.D. Dissertation*, University of Delaware.
22. Wunderlich, J.T., S. Chen, D. Pino, and T. Rahman (1993). Software architecture for a kinematically dissimilar master-slave telerobot. In *Proceedings of SPIE Int'l Conference on Telemanipulator Technology and Space Telerobotics*, Boston, MA: Vol. (2057). (pp. 187-198). SPIE Press.
23. Wunderlich, J.T., and Elias, J. (1993). Design of an artificial dendritic tree VLSI microprocessor. U.Del. research report, 1993.
24. Wunderlich, J.T. (1992). A vector-register neural-network microprocessor with on-chip learning. *Masters Thesis*, Pennsylvania State University.
25. Wunderlich, J.T. (1999). Focusing on the blurry distinction between microprocessors and microcontrollers. In *Proceedings of 1999 ASEE Annual Conference & Exposition, Charlotte, NC*: (session 3547), [CD-ROM]. ASEE Publications.
26. Wunderlich, J.T. (2003). Functional verification of SMP, MPP, and vector-register supercomputers through controlled randomness. In *Proceedings of IEEE SoutheastCon, Ocho Rios, Jamaica*, M. Curtis (Ed.): (pp. 117-122). IEEE Press.
27. Wunderlich, J.T. (1997). Random number generator macros for the system assurance kernel product assurance macro interface. *Systems Programmer's User Manual for IBM S/390 Systems Architecture Verification*, Poughkeepsie, NY.
28. Patterson, R.L.. and Hammoud, Ahmad. (2004) Reliability of Electronics for Cryogenic Space Applications Being Assessed. *NASA Research and Technology 2004*.
29. Pappalardo, R.T. (2006). Europa: processes and habitability (presentation). Pasadena, CA: Jet Propulsion Laboratory, National Aeronautics and Space Administration
30. Henderson, S., Shreshtha, S., Wunderlich, J.T. (2004). A high speed AUV test platform *(submitted to military conference)*.
31. Painter, J. G. (2008). Vision system for Wunderbot IV autonomous robot. *Elizabethtown College research report.*
32. Crouse, J. (2008). The joint architecture for unmanned systems: a subsystem of the wunderbot 4. *Elizabethtown College research report.*
33. Painter, J. G., Coleman, D., Crouse, J., Yorgey, C., and Wunderlich, J.T. (2008) Wunderbot 4 IGVC report. *Judged and published on-line by IGVC.*
34. Boeing Company and NASA (1971) *LRV operations handbook*. Document LS006-002-2H.
35. Boeing Company and NASA (1971*) LRV operations handbook. appendix A performance data*. Document LS006-002-2H.
36. Carsen, A., Rankin, J., Fuguson, D., and Stentz, A. (2007). Global path planning on board the mars exploration rovers. *In Proceedings of the IEEE Aerospace Conference, 2007. IEEE Press. (available at http://marstech.jpl.nasa.gov/publications/z02_0102.pdf)*
37. Bajracharya, M., Maimone, M.W., and Helmick, D. (2008). Autonomy for mars rovers: past, present, and future. In *Computer*: December, 2008. (pp. 44-50). *IEEE Press. (available at http://marstech.jpl.nasa.gov/publications/z02_0102.pdf)*
38. International Workshop on Europa Lander: Science Goals and Experiments, February 9-13, 2009, Moscow, Russia. *(available at http://www.iki.rssi.ru/conf/2009elw)*
39. NASA Home Page (http://www.nasa.gov/)
40. European Space Agency Home Page (http://www.esa.int/esaCP/index.html)
41. JPL/CalTech "BEACON *eSpace*" database (http://trs-new.jpl.nasa.gov/dspace/)
42. NASA Technical Reports Server (http://ntrs.nasa.gov/search.jsp)
43. JPL/CalTech PhotoJournal (http://photojournal.jpl.nasa.gov/)
44. Harvard SOA/NASA Astrophysics Data System (http://adsabs.harvard.edu/index.html)
45. SOA/NASA Wunderlich "Library" (http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?library&libname=wunderlich&libid=4a0f09cf26l)
46. National Geographic Archive (http://ngm.nationalgeographic.com/archives)
47. Wunderlich, J.T.(2011). Designing robot autonomy: how tightly should we hold the leash? *The 5th Int'l Conference on Design Principles and Practices,* Rome Italy.