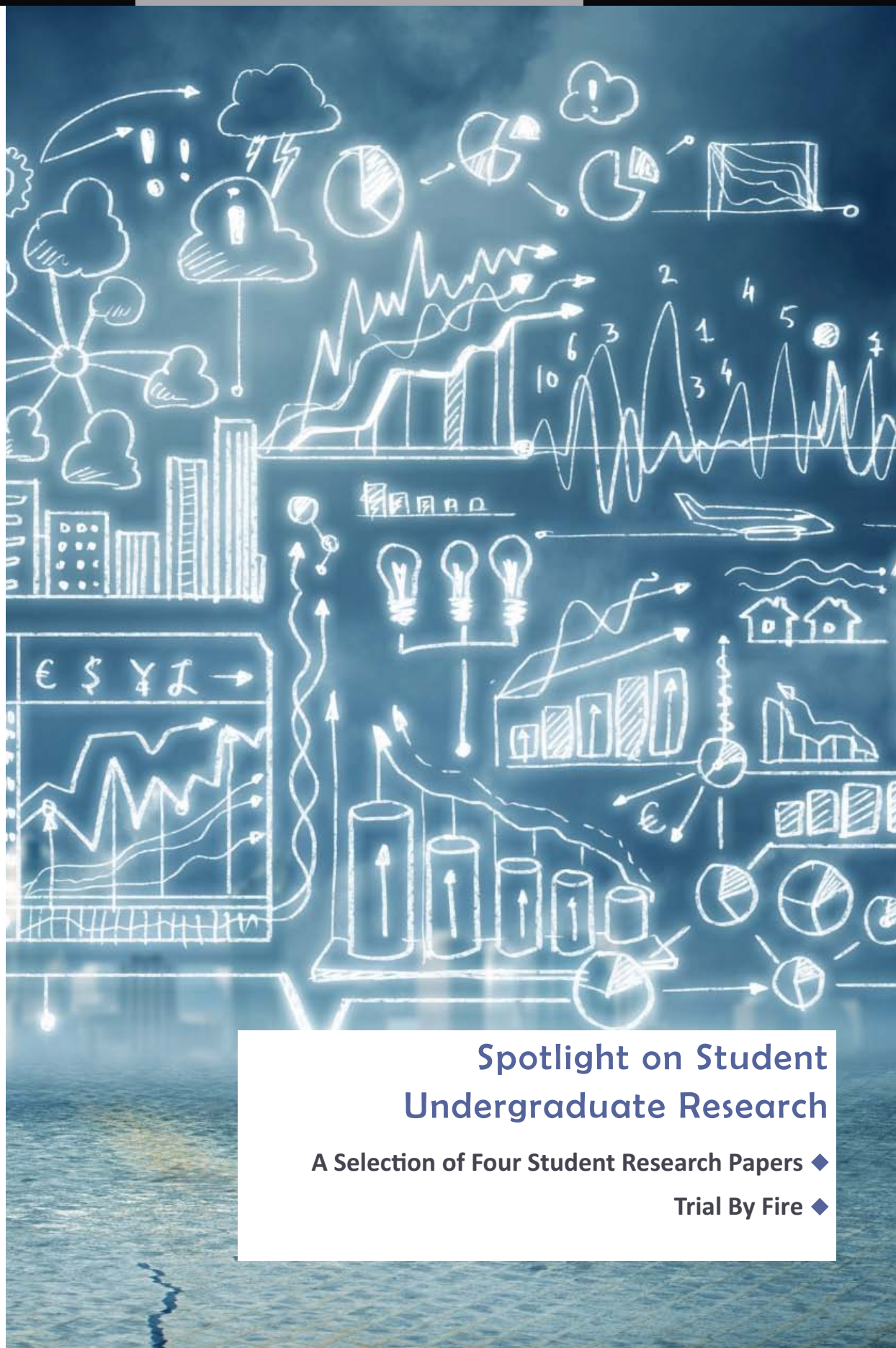


THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu



Spotlight on Student Undergraduate Research

A Selection of Four Student Research Papers ♦

Trial By Fire ♦

November 2014 Vol. 110 / No. 3



IEEE-HKN AWARD NOMINATIONS



As an honor society, IEEE-Eta Kappa Nu has plenty of opportunities designed to promote and encourage outstanding students, educators and members.

Visit www.hkn.org/awards to view the awards programs, awards committees, list of past winners, nomination criteria and deadlines.

Outstanding Young Professional Award

Presented annually to an exceptional young professional who has demonstrated significant contributions early in his or her professional career. (Deadline: 30 April)

Vladimir Karapetoff Outstanding Technical Achievement Award

Recognizes an individual who has distinguished him or herself through an invention, development, or discovery in the field of electrical or computer technology. (Deadline: 30 April)

Outstanding Student Award

Annually identifies a senior who has proven outstanding scholastic excellence, high moral character, and exemplary service to classmates, university, community and country. (Deadline: 30 June)

Outstanding Chapter Award

Singles out chapters that have shown excellence in their activities and service at the department, university and community levels. Winners are determined by their required Annual Chapter Reports for the preceding academic year. (Deadline: 15 October)

C. Holmes MacDonald Outstanding Teaching Award

Presented annually to a dedicated young professor who has proven exceptional dedication to education and has found the balance between pressure for research and publications and enthusiasm and classroom enthusiasm and creativity. (Deadline: 30 April)

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Presented annually to recognize those members who have devoted years of service to the society, resulting in significant benefits to all of the society's members. (Deadline: 30 April)



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ISSN-0006-0809 Vol. 110 / No. 3

THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

November 2014 Features

10

Student Research

A Selection of Four Student Research Papers:

Utilizing Computational Electromagnetics for the Advancement of Photonic Processor Communications

By Jelena Notaros

New Completion-Tree Topology for Quasi-delay Insensitive Logic

By Anjian Wu and Alain J. Martin

Telemetry Processor Design for a Remotely Operated Vehicle

By Keenan Johnson

GazePointer: Computer Vision Based Eye Gaze Tracking for Human-Computer Interaction

By Muhammad Usman Ghani and Muhammad Adnan Siddique

38

Trial By Fire

By Robin R. Murphy

*Activities of the Rescue Robots at the
World Trade Center from 11–21 September 2001*

Departments

Members and Chapters

53 Key Chapter Update

56 Member Profiles

60 Lambda Beta Chapter Outreach

News and Updates

8 In Memoriam

33 Member Insurance

34 Sections Congress Recap

36 Strategic Direction

Society Spotlight

55 Aerospace and Electronic
Systems Society

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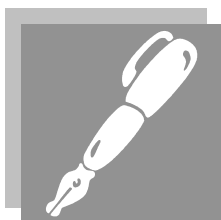
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LETTER FROM THE PRESIDENT

DR. JOHN A. ORR
Alpha Chapter

Dear IEEE-Eta Kappa Nu Members and Friends:

It has been a real honor as well as a great pleasure to serve as president of IEEE-HKN for the past two years.

The most important message that I would like to deliver in this letter is to say, "Thank you" to everyone who has stepped forward to help IEEE-HKN continue to accomplish and enhance its mission, to establish it as a vital part of IEEE, and to develop a clear vision for our role in the twenty-first century.

Our wonderful staff, Nancy Ostin and Amy Recine, have brought great vitality and creativity to our activities. The members of the Board of Governors have demonstrated deep commitment as well as prudence and good judgment in guiding and ensuring our future. The addition of a student member on the Board has already yielded benefits. Steve Watkins, Editor-in-Chief of THE BRIDGE, merits thanks and congratulations for the attractive publication that consistently contains important content that is of interest across the spectrum of our student and alumni members.

Two more groups deserve our thanks: the committee members and chairs who work behind the scenes on awards and other important activities, and certainly our chapter advisers who are absolutely key to the continued vitality and success of IEEE-HKN.

I have had the opportunity to install a number of new chapters. That is always a wonderful experience. I have found the commitment of the inaugural officers and faculty advisers to be quite inspiring. And it is always worthwhile to visit another institution and see their approach to engineering education. There is always something to learn!

Thinking back to my own induction into Alpha chapter in 1968, I marvel at how far my profession of electrical and computer engineering has come. A large portion of that progress has been directly due to IEEE-HKN members, and I am confident that their membership helped to educate and inspire them to their professional success.

My very best wishes,

Phone + 1 508-831-5273

Email: j.orr@ieee.org



LETTER FROM THE EDITOR-IN-CHIEF



DR. STEVE E. WATKINS

Gamma Theta Chapter

Dear IEEE-Eta Kappa Nu Members and Friends:

THE BRIDGE magazine was recognized with a 2014 APEX Award of Excellence in the most improved category of this international competition for communication professionals (www.apexawards.com). I thank the editorial board, the IEEE-HKN staff, and our contributors for making the magazine a publication worthy of note!

The theme of this issue of the magazine is "Spotlight on Student Undergraduate Research." Engineering students have many opportunities to go beyond lectures and associated laboratories and to engage in research even as undergraduates. IEEE-HKN members have the background and initiative to excel in these activities. Whether the research is done through honors activities, laboratory assistantships, or competition design teams, solving real problems, seeking new knowledge, and partnering with faculty are invaluable experiences. In this issue we have examples of undergraduate work related to photonics, logic design, computer vision, and vehicular instrumentation as well as a reprint showing engineering student contributions during a signature crisis. I hope that these examples will stir other undergraduates to seek out similar opportunities.

The excitement of engineering work is not new. Each generation should relate Isaac Newton's version of an ancient expression, "If I have seen further it is by standing on ye shoulders of Giants." I recently found some old laboratory equipment at my institution. Most of the instruments were still in working order and were designed with elegant wood and brass trappings. The instruments included the telegraph straight key and sounder shown below. I identified the item as a telegraph learner set which was sold through the 1939 Radio Shack catalog for \$2.94. Note the mahogany base, the nickel-plated lever, and brass posts. I can easily imagine these instruments in the up-to-date electrical engineering laboratory of the 1940s. These are the tools that trained those that created our current technologies. It will be interesting to see how the tools change in the coming decades.

The telegraph set would have transmitted "HKN" as ".... -.- -."? Can you think of any alternative ways to transmit HKN? You can contact me at steve.e.watkins@ieee.org.

Best regards,

Steve E. Watkins

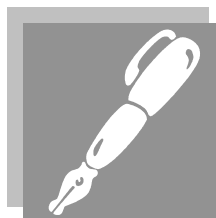
Phone + 1 573-341-6321

Email: steve.e.watkins@ieee.org



Telegraph Learner Set with Key and Sounder (c. 1939).

LETTER FROM THE DIRECTOR

*NANCY M. OSTIN, CAE*

Dear IEEE-Eta Kappa Nu Members and Friends:

I am very excited about this issue of THE BRIDGE. This issue on “Student Research” was made possible by the dedication and extraordinary effort of Editor-in-Chief Steve Watkins and the Editorial Board. The society’s amazing volunteers make it possible for IEEE-HKN to offer these kind of opportunities to students.

IEEE-HKN is in the midst of a renaissance. The mission and vision of IEEE-HKN is as relevant today as it was 110 years ago when the society was founded on 28 October 1904. The principals that define IEEE-HKN – the critical success skills developed and industry recognition garnered – have translated into growth in membership, the revitalization of dormant chapters, and interest from universities around the world to form new IEEE-HKN chapters.

Our annual student leadership conference will be held 20-21 March 2015, and hosted by Mu chapter at the University of California, Berkeley. It is their 100th chapter anniversary. The proximity to Silicon Valley and the society’s combined industry contacts promise to translate into a conference no one will want to miss. Registration is free for current IEEE-HKN students.

Alumni, please consider supporting the conference – a donation of \$110 (to recognize our 110th anniversary) will cover the cost for one student to attend the program. To make your contribution, please select the Student Leadership Conference on the [IEEE Foundation site](#).

IEEE-HKN recently announced the launch of our [Virtual Campus](#) – an online community with resources to train chapters and officers, share best practices and documents, and provide a chat feature for members to communicate. All are invited to learn more about the Alumni-Student Project Mentoring program – a program aimed at partnering alumni subject matter experts with students on a capstone or senior project.

As a final note, as his term as President winds down, I wish to extend a special thank you to Dr. John Orr. His leadership and guidance over the past two years provided a strong foundation for IEEE-HKN and established a plan for the future that includes implementing the recently-adopted strategic plan. Please join me in thanking him and extending our appreciation to all of the volunteers who work to further mission and vision of IEEE-HKN.

A handwritten signature in black ink, reading "Nancy M. Ostin".

Phone + 1 732-465-6611

Email: n.ostin@ieee.org



Save the date: 20-21 March 2015

IEEE-HKN 2015 Student Leadership Conference in Berkeley, California



Join the Mu Chapter at the IEEE-HKN 2015 Student Leadership Conference in Berkeley, California.

The annual IEEE-HKN Student Leadership Conference is a signature program of the society and is an amazing opportunity for your chapter to meet with other officers, members, faculty advisers, members of the Board of Governors and staff. The 2015 event will be held on 20-21 March by the Mu chapter at the University of California, Berkeley. The conference includes opportunities for professional development, leadership training and networking. There is no registration cost for IEEE-HKN students and faculty advisers (includes meals during the event). In addition, every chapter and every faculty adviser are eligible to receive up to \$250 after the conference to defer costs related to travel, lodging and more.

How can chapters raise any additional funds necessary for members to attend the conference? There are several ways you may be able to find assistance, including:

- ◆ Ask your department head or dean: In many cases, the department has the funds to help cover a portion of your costs. This may require your chapter creating a proposal. To view samples of what other chapters have successfully used, visit the Resource Library at the [IEEE-HKN Virtual Campus](#).
- ◆ Ask your IEEE Section: IEEE Sections often have funds to support student programs. Contact your IEEE Section Chair and ask about the process. Other societies and communities at IEEE may also have funds. [Learn about these groups online](#).
- ◆ Ask your Alumni: Alumni are interested in the current activities of students at their alma mater. In the past, some have contributed airline miles and have directly sponsored travel costs.
- ◆ Fundraise: Plan now for an activity or series of events to raise money. Examples from other chapters include hosting Pizza Fridays, bake sales and more – check the Resource Library at the [IEEE-HKN Virtual Campus](#) for more best practices.

Start planning for you and your chapter now. Registration will be available starting in December through the IEEE-HKN [website](#).

IN MEMORIAM



IEEE-LCD Pioneer Made Things Crystal Clear

The Institute mourns the loss of IEEE Fellow George Heilmeier

By Amanda Davis, Senior Editorial Assistant, *"The Institute"*

This article originally appeared in IEEE's *The Institute*.

Every day you're likely to encounter at least one LCD display—it's not only found in televisions and laptops, but also in calculators, watches, and dashboard displays in cars. This and other technology wouldn't be possible without the work of IEEE Fellow George Heilmeier. An IEEE Medal of Honor recipient and chairman emeritus of Bellcore (now Telcordia Technologies), Heilmeier died on 21 April at the age of 77.

He began his career in 1952 at RCA Laboratories, in Princeton, N.J., where he worked on parametric amplification, tunnel diode down-converters, millimeter wave generation, ferroelectric thin film devices, and organic semiconductors. He also studied electro-optic effects in molecular and liquid crystals.

In 1964 and 1965 Heilmeier discovered several new electro-optic effects in liquid crystals, which led to the first working LCDs based on what he called the dynamic scattering mode (DSM). Application of a voltage to a DSM display switches the initially clear transparent liquid crystal layer into a somewhat opaque, milky state. The first functional active-matrix LCD panel was introduced 1972 by Westinghouse, in Pittsburgh, Pa. This technology would later be used in such portable devices as Nintendo's handheld Game Boy videogame and the Toshiba T1100, the first commercially successful IBM-compatible laptop.

Heilmeier's contribution to LCDs was recognized with numerous awards, including the 1976 IEEE David Sarnoff Award and the 1991 U.S. National Medal of Science. He received the 1997 IEEE Medal of Honor for the "discovery and initial development of electro-optic effects in liquid crystals." Heilmeier received the 1993 Vladimir Karapetoff Outstanding Technical Achievement Award from Eta Kappa Nu (HKN), IEEE's honor society. He was inducted into HKN as a student in 1958 and was named an Eminent Member in 2000.

In 2006 his work was honored with an IEEE Milestone in Electrical Engineering and Computing. Most recently, Heilmeier shared the National Academy of Engineering's 2012 Charles Stark Draper Award with RCA colleagues Wolfgang Helfrich and Martin Schadt, as well as T. Peter Brody, a Westinghouse engineer who led the development of the active-matrix LCD display. They were recognized for the "engineering development of the liquid crystal display (LCD) utilized in billions of consumer and professional devices."

LEADERSHIP

In the 1970s Heilmeier followed a different calling—working for the U.S. government. He was appointed White House Fellow in 1970 by President Richard Nixon. Fellows spend a year as full-time, paid assistants to top-ranking government officials. He was an assistant to the Secretary of Defense, helping to plan long-term R&D projects. The following year he was named assistant director of defense R&D and electronic and physical sciences.

In 1975 Heilmeier was appointed director of the Defense Advanced Research Projects Agency (DARPA) and initiated major projects for stealth aircraft, space-based lasers, space-based infrared technology, and artificial intelligence. While working for the agency he was twice awarded the Department of Defense's Distinguished Civilian Service Medal—the highest civilian award given by the DoD.

Heilmeier left DARPA in 1977 to join Texas Instruments, in Dallas, where he managed R&D projects in petroleum exploration, systems technology, microelectronics, and software. The following year he was appointed vice president of corporate research, development, engineering and strategic planning. Heilmeier was named senior vice president and chief technology officer in 1983.

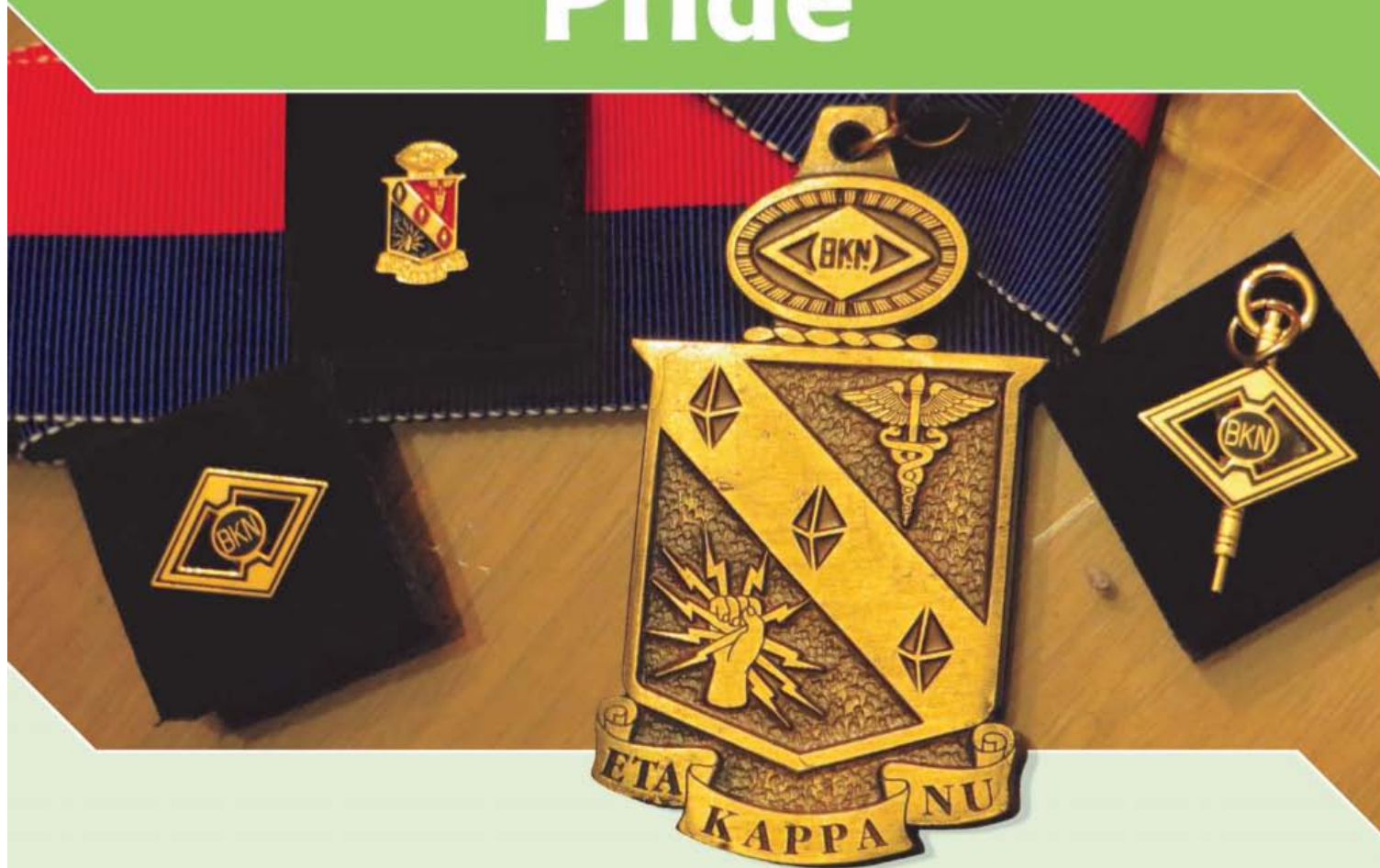
In 1991, he was named president and CEO of Bellcore, a telecommunications company, in Livingston, N.J., and served in that position until 1996. He was named chairman emeritus in 1997.

For more information on Heilmeier's career and contributions, visit the [IEEE Global History Network](http://www.ieee.org/globalhistory).



George Heilmeier (center) receives the 1968 Eta Kappa Nu "Outstanding Young Electrical and Computer Engineer Award."
Photo Credit: IEEE Global History Network

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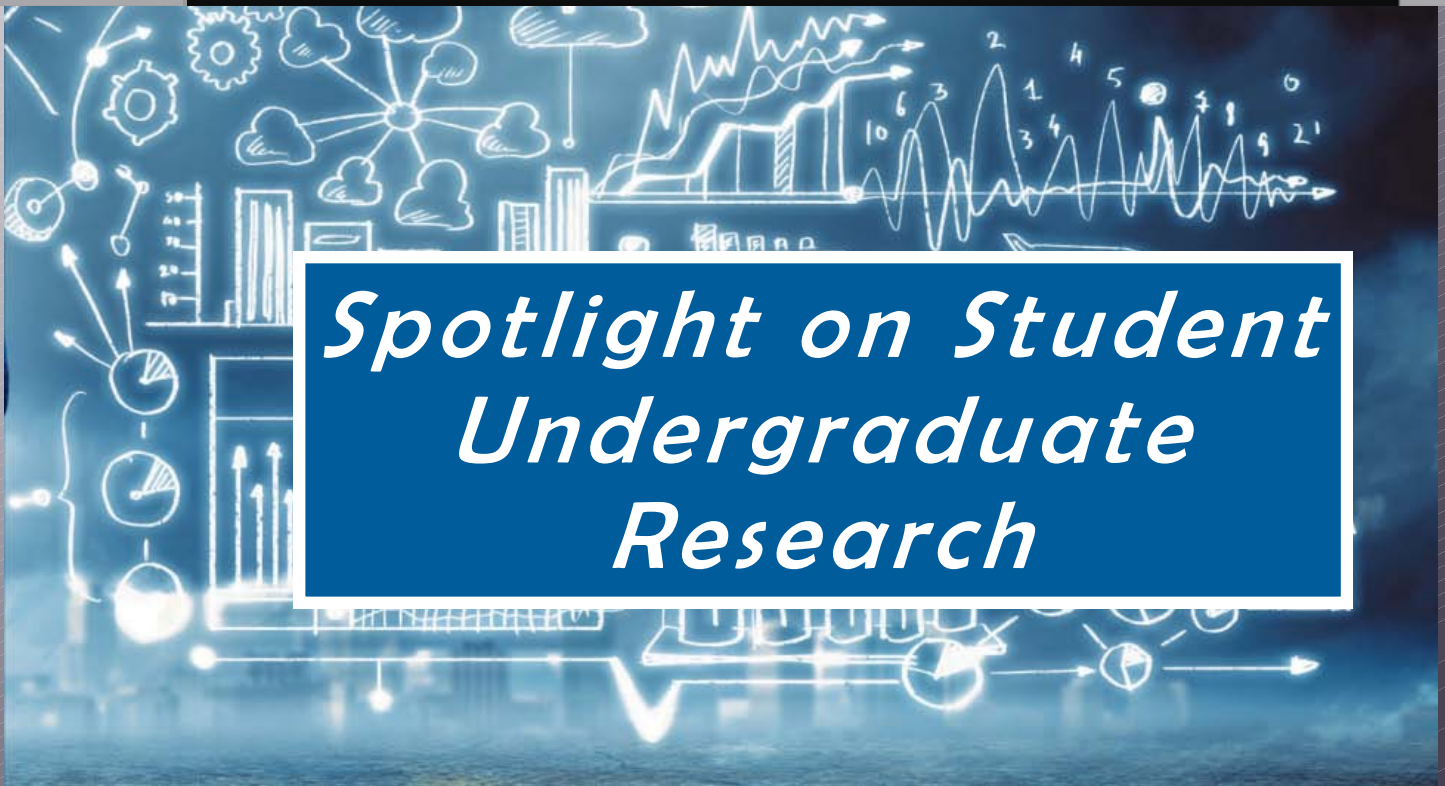
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Spotlight on Student Undergraduate Research

The purpose of this issue is to provide a publication opportunity to undergraduates conducting research and to showcase opportunities for such research. We have excellent contributions from undergraduates at the University of Colorado Boulder, California Institute of Technology, Missouri University of Science and Technology, and COMSTAT Institute of Information Technology (Lahore, Pakistan). One student author served as the guest editor and had the following observations concerning undergraduate research:

When I started my college career, I had no idea what “research” was. I imagined scientists buried deep within secret underground facilities performing unimaginably complex tasks. Research seemed a lofty and almost unattainable reality that I would likely never achieve. Ironically, one of the first things I did at my University was to attend a meeting of a student club that had the goal of designing and performing interesting research experiments. Suddenly research became an achievable, exciting and effective way to add breadth to an undergraduate career.

In my opinion there are three types of learning experiences in an undergraduate career: a solid theoretical foundation, practical implementation experience, and innovative concept exploration. In the S.T.E.M. (Science, Technology, Engineering, & Mathematics) fields, the solid theoretical foundation comes largely from the classes and curriculum. The practical, implementation experience often comes from a mix of student projects and internships. However, the third category, innovative concept exploration can often only be experienced by performing some sort of research. Classes generally focus on things that have been done in the past and practical experience generally requires immediate results from the current technologies. Thus student research can offer the chance to reach for the stars and try things that have never been done.

The articles in this issue provide a small sample of different areas and avenues for undergraduate research. They show that it is possible to explore interesting and meaningful topics as an undergraduate student even with limited resources. The exercise of research is a fun and important one for all students, including undergraduates. Interesting opportunities are available for the student who takes the initiative to seek them out or to create a new project. I encourage others to constantly brainstorm new ideas that they feel could be interesting or plausible. If you end up with an idea that really motivates you, by all means try to bring that idea into reality in some way. The experience will be one of the most rewarding and helpful things you can do in your undergraduate career.

-- Keenan Johnson, Guest Student Editor, Gamma Theta Chapter

Utilizing Computational Electromagnetics for the Advancement of Photonic Processor Communications

By Jelena Notaros
University of Colorado Boulder
Rho Chapter

Introduction

Processor communication links are an integral aspect of current multicore processor technology. Using optical signals, the field of photonics promises to redesign these communications to allow for more energy efficient and higher speed computing.

With photonics implementing technology on the wavelength scale, numerical methods have become an essential tool for the design of the photonic devices that compose these communication links. Specifically, current research efforts have focused on the creation of numerical band structure solvers for design of periodic photonic devices – essential concepts in photonic processor communications.

This article highlights a recently proposed complex-wavevector numerical solver and presents practical applications of the solver to photonic device design.

Moore's Law

In 1965, Gordon Moore predicted how component density in integrated circuits would increase [1]. His prediction, now referred to as Moore's Law, has proven true – transistors have been decreasing in size and the number of transistors on a chip has been increasing exponentially. Although this increase in transistors initially allowed for faster processors, in 2003, the rate of increase in processor speeds began to flatten out since higher speeds would cause the now extremely densely integrated transistors to overheat [2].

At that time, processors began to utilize multicore systems which require communication links between individual cores and memory. Although multiple cores allowed for a renewed increase in operating speed, the resulting complex communication links began to consume a large amount of power.

Photonics in Processors

To combat this increase in energy usage, current research efforts in photonics propose redesigning processor communications using light and photonic devices in place of electrical signals and microelectronics. This new technology promises to lead to extremely energy efficient and high speed computing for use in applications ranging from supercomputers to everyday electronics such as laptops and smartphones.

Specifically, the DARPA POEM program, a collaboration between the University of Colorado Boulder, Massachusetts Institute of Technology, and University of California Berkeley, is focusing on addressing electrical communication link limitations by developing photonic technology for fabrication directly in the complementary metal-oxide-semiconductor (CMOS) process – the prevalent microelectronics fabrication process (Fig. 1). By utilizing this method, this new technology will allow for complete integration with all aspects of current processor design to enable seamless intra-chip and off-chip photonic communications [3].

Numerical Solvers

To achieve this photonic communication link, nanophotonic devices, the building blocks of the proposed link, must be designed efficiently and rigorously. Since these nanophotonic devices manipulate light on the wavelength scale, simple analysis of the devices is inaccurate and numerical solvers are critical to their invention. Taking as input the device's geometry and material composition, these solvers compute how the device manipulates inputted optical signals by dividing the device into a grid, implementing Maxwell's equations – the laws that govern electromagnetic fields – at every point on the grid, and, finally, solving the resulting system of equations often as an eigenvalue problem.

Many of these photonic devices, such as grating couplers, waveguide crossings, and photonic crystals, are periodic – they consist of a unit cell which is repeated periodically to form the device's structure.

Due to their periodic nature, a natural way to design these structures is through photonic band structure analysis using numerical band solvers [4]. Traditionally, band solvers have been coded with an input of real wavevector, k , and output of complex angular frequency, $\omega = \text{Re}(\omega) + j\text{Im}(\omega)$. For device design purposes, where devices are powered using a laser that emits one real frequency, the complex frequency outputs of these traditional solvers are not optimized. Instead, it is of practical necessity to have a solver where the real target laser frequency is specified and the complex wavevector, $k = \text{Re}(k) + j\text{Im}(k)$, is solved for as a function of frequency [5, 6].

Complex Wavevector Theory

To implement a complex-wavevector solver, Maxwell's equations are modified to solve for a periodic device and to have outputs of complex wavevector and electric field. First, starting from Maxwell's equations, the wave equation for the transverse electric field, $\Psi(x,y)$, of a two-dimensional structure is derived

$$[\partial_x^2 + \partial_y^2 + k_0^2 n^2(x,y)]\Psi(x,y) = 0$$

Where k_0 is the free-space wavenumber (proportional to frequency) and $n(x,y)$ is the refractive index distribution of the structure. The wave equation is then modified using Bloch theorem to account for periodicity and is discretized on the Yee interleaved grid [7] to produce the final equation to be solved numerically

$$[\hat{\partial}_x \tilde{\partial}_x + \hat{\partial}_y \tilde{\partial}_y + ik(\hat{\partial}_x + \tilde{\partial}_x) - k^2 + k_0^2 n_{m,n}^2]\Phi_{m,n} = 0$$

With $\hat{\partial}$ and $\tilde{\partial}$ being forward and backward numerical derivatives, k standing for the wavevector in coordinate x , and $\Phi(x,y)$ being the unit-cell electric field. This final equation is implemented on the computational grid in the form of a matrix and is solved as an eigenvalue problem, with k being the eigenvalue and $\Phi(x,y)$ the eigenvector.

Analytical Validation

When a numerical solver is developed, the accuracy and validity of the presented theory can be demonstrated through comparison with analytical solutions derived in literature and cross-referencing with other numerical tools. For validation of the proposed complex-wavevector solver, a two-material quarter-wave stack medium is simulated using both one- and two-dimensional versions of the solver and the resulting band structure is compared to the analytical solution [8].

As observed from Fig. 2, varying the input frequency (proportional to normalized free-space wavenumber, $k_0 a$) results in a variation of the normalized wavevector, ka , in both the real and imaginary domains. When $\text{Re}(k)$, shown in blue,

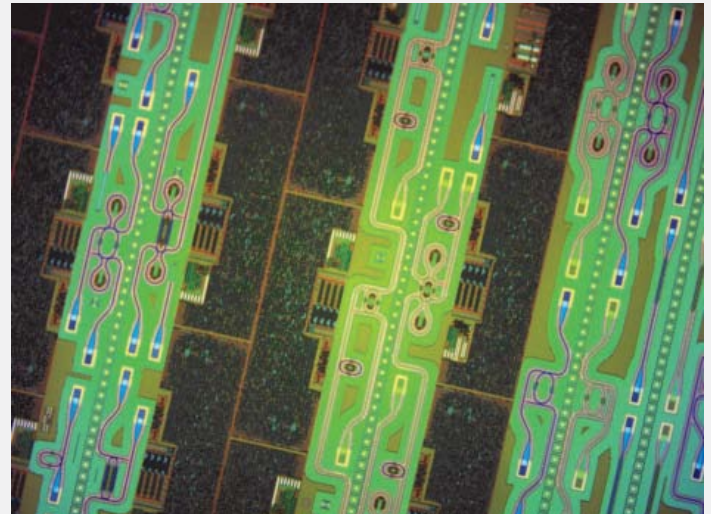


Fig. 1: Microscopic view of a silicon chip developed by the POEM team fabricated in the CMOS process demonstrating the novel integration of photonic devices with microelectronics.
Photo courtesy of Jason Orcutt (MIT).

reaches a value of π/a , the wavevector protrudes into the complex domain and a bandgap is formed in the material. This bandgap represents the group of frequencies not supported for propagation in the structure – similar to a circuit's bandstop filter.

Additionally, from the band structure, excellent agreement of numerical results obtained by both the one- and two-dimensional solvers with the analytical solution is seen. Analytically, the structure's bandgap size is computed to be $(\Delta k_0 a)_{ana} = 0.634$ whereas both one- and two-dimensional solvers yield $(\Delta k_0 a)_{num} = 0.635$. The simulation results prove to be very accurate, therefore verifying and validating the theory and numerical implementation of the complex-wavevector solver.

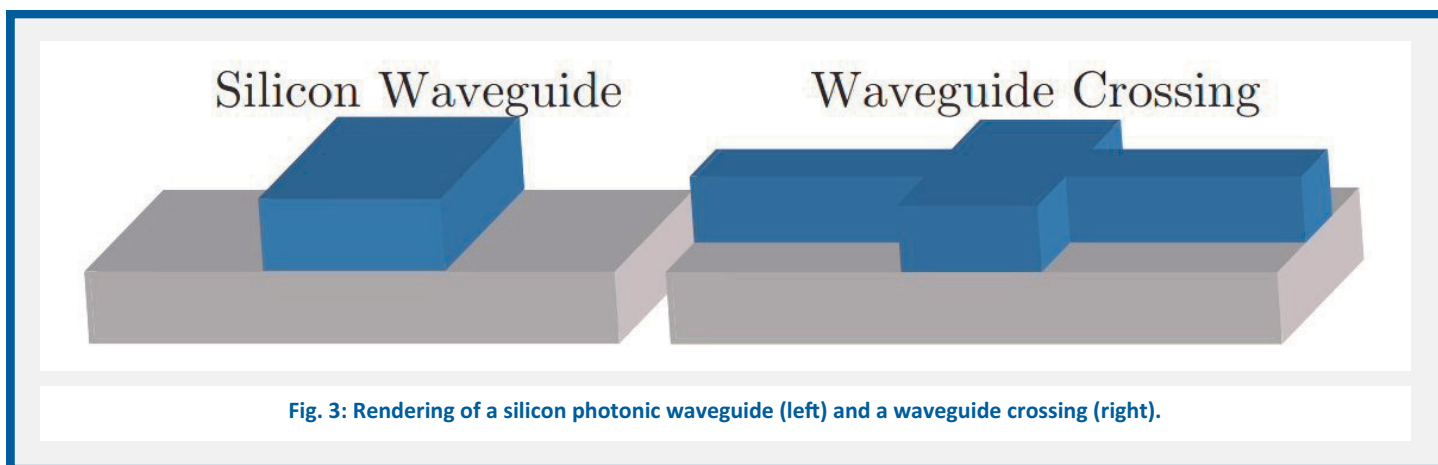
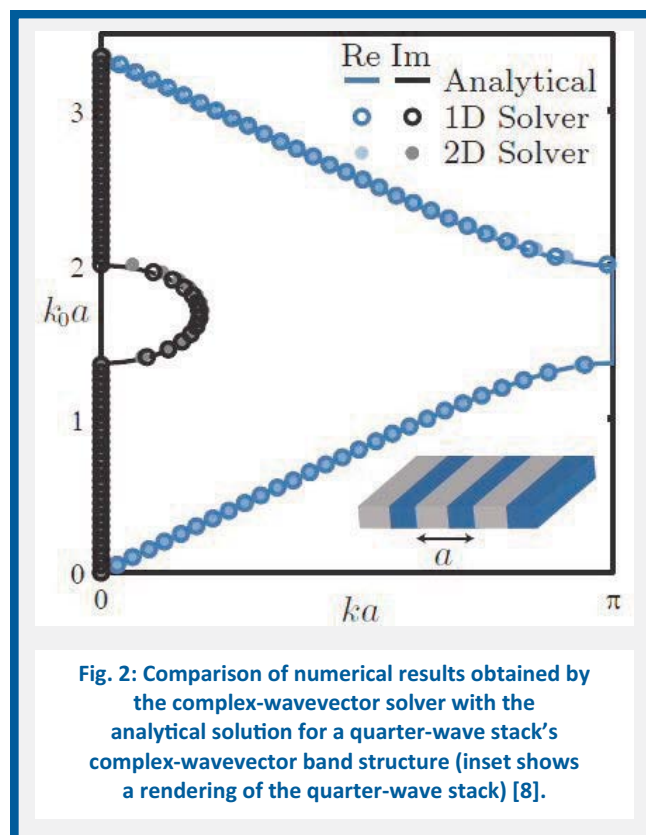
Device Design Applications

With validation of the solver complete, current research efforts are focused on utilizing the complex-wavevector solver to optimize the design of various periodic photonic devices that act as essential building blocks in photonic communication systems.

One of these useful photonic devices which lends itself to band structure analysis is the waveguide crossing [9]. Photonic waveguides, often fabricated as strips of silicon on top of silica (Fig. 3), guide laser light to devices on a chip, similar to wires in an electric circuit. To allow for dense device integration, these waveguides must cross just as electrical wires cross in a complex electrical circuit. Although these crossings allow for denser integration, each crossing causes losses to occur in the system. If two bare wires crossing are visualized, it is apparent that the current-carrying wire loses some of its current to the wire touching it. This same concept applies to photonic waveguide crossings. Each crossing causes some of the power in the system to be radiated out of the structure and lost (Fig. 4a).

Using the complex-wavevector solver, this undesirable loss can be minimized. By optimizing the waveguide crossing's dimensions, the supported field is made to exhibit an ultra-low-loss characteristic decreasing crossing loss to an extremely low 0.06 dB loss per crossing (Fig. 4b).

In addition to optimizing waveguide crossings for dense device integration, the complex-wavevector solver is being applied to design efficient grating couplers – essential for transferring light from a chip to testing equipment – and photonic crystals – devices that act like extremely high quality photonic filters.



Conclusions

Complex-wavevector solvers have the capability to enable powerful techniques for rigorous synthesis of advanced periodic photonic devices. These periodic devices are essential components of photonic processor communications and their optimization is vital for the establishment of high bandwidth, low energy, integrated communication links. These improved photonic communications will allow for more energy efficient and higher speed computing with the potential to affect the future of technology.

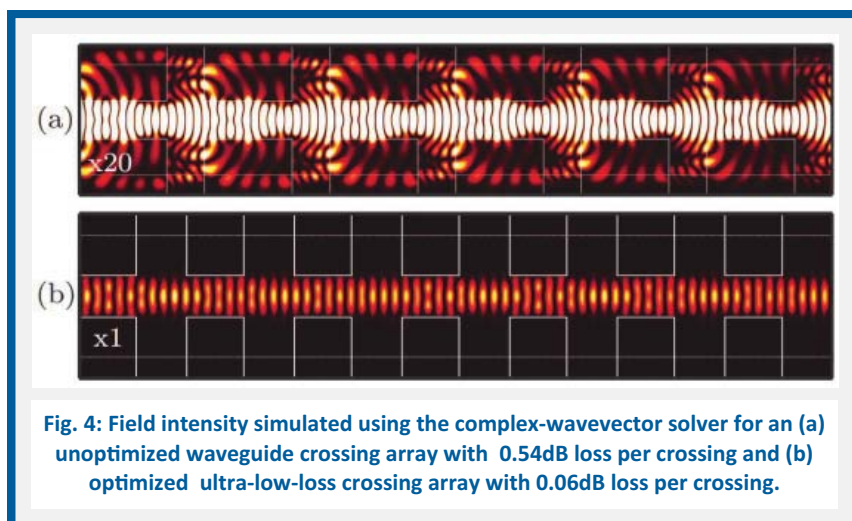
For further in-depth technical reading on the complex-wavevector solver for photonic applications refer to Refs. [5, 6].

References

- [1] G. Moore, "Cramming More Components onto Integrated Circuits," *Electronics*, 38(8), 114-117, 1965.
- [2] J. Meindl, "Beyond Moore's Law: the interconnect era," *Computing in Science & Engineering* 5(1), 20-24 (2003).
- [3] J. S. Orcutt, B. Moss, C. Sun, *et al.*, "An Open Foundry Platform for High-Performance Electronic-Photonic Integration," *Optics Express* 20, 12222-12232 (2012).
- [4] S. Johnson and J. Joannopoulos, "Block-iterative frequency-domain methods for Maxwell's equations in a planewave basis," *Opt. Express* 8(3), 173-190 (2001).
- [5] J. Notaros and M. A. Popović, "Finite-Difference Complex Wavevector Band Structure Solver for Nanophotonics Applications," in *Proc. Integrated Photonics Research (IPR)*, July 2014, paper IT1A.3.
- [6] J. Notaros and M. A. Popović, "Analysis of Leaky-Wave Microphotonic Structures with a Complex-Wavevector Photonic Band Structure Solver," in *Proc. Frontiers in Optics (FIO)*, October 2014, paper FTh4D.3.
- [7] W. Chew, "Electromagnetic theory on a lattice," *Journal of Appl. Physics* 75(10), 4843-4850 (1994).
- [8] A. Yariv and P. Yeh, *Photonics*, (Oxford University Press, 2007), Chap. 12.
- [9] Y. Liu, J. M. Shainline, X. Zeng, and M. Popović, "Ultra-low-loss CMOS-compatible waveguide crossing arrays based on multimode Bloch waves and imaginary coupling," *Opt. Lett.* 39, 335-338 (2014).

How Work Was Done and Acknowledgments

The solver presented was completed independently, by the author, as a research assistant in the Nanophotonic Systems Laboratory under the guidance of Professor Miloš Popović. To the best of the author's knowledge, this is the first demonstration of a finite-difference complex-wavevector band structure solver. This work was supported by the University of Colorado Discovery Learning Apprenticeship undergraduate research program and National Science Foundation award number ECCS-1128709. The author would like to thank her advisor, Professor Popović, for his guidance and commitment to student success.



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New Completion-Tree Topology for Quasi-delay Insensitive Logic

By Anjian Wu, Student, IEEE, and
Alain J. Martin, Member, IEEE
California Institute of Technology

Abstract

Asynchronous digital logic designs often require building circuitry to check when the outputs are valid. The validity of inputs and outputs (in the form of 1-of-N channels) are determined by completion-sensing circuitry (or completion trees), which are often constructed using trees of Muller-C elements with output feedback for hysteresis. This approach is often disadvantageous since each element requires an inverting feedback. Our new proposed design attempts to address this issue by consolidating the feedback into one from the output of the completion-sensing trees, instead of individual feedbacks at the unit Muller-C element level. This paper will use simple RC delay models and HSPICE simulations from layout extractions to characterize the performance improvement of this new implementation. For certain applications of medium to large fan-out loads, we will show that the proposed design has strong advantages in improving delay performance.

Introduction

An asynchronous circuit, or delay-insensitive circuit, is a sequential digital logic circuit that does not use a clock signal. Instead, it uses signals that indicate completion of an instruction or operation usually specified by a handshake protocol [1]. This technique often involves designing the data path using dual-rail or 1-of-N encoding and requires completion sensing circuits (or trees) to check when the outputs are valid [2]. Because every block of

logic requires completion sensing for validity of outputs, this family of circuits are fundamental and ubiquitous to asynchronous digital design.

The basic building block of completion sensing is the single Muller-C element (or C-element) [3]. It has two input signals (X and Y) and one output signal (Z) (Figure 3a). When both inputs X and Y go high, the output Z goes high. The output Z then remains high until X and Y both become low, at which the output Z returns low and the process repeats (1).

$$Z = XY + XZ + YZ \quad (1)$$

Thus the output of the C-element reflects the inputs when the states of all inputs match. The output then remains in this state until the inputs all transition to the other state. By stacking many of these single C-Elements into cascaded trees, any number of input completion detection can be created (Figure 1).

There are various C-element implementations in complementary metal-oxide-semiconductor (CMOS)

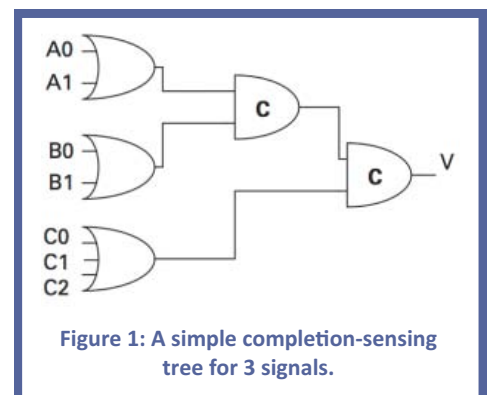
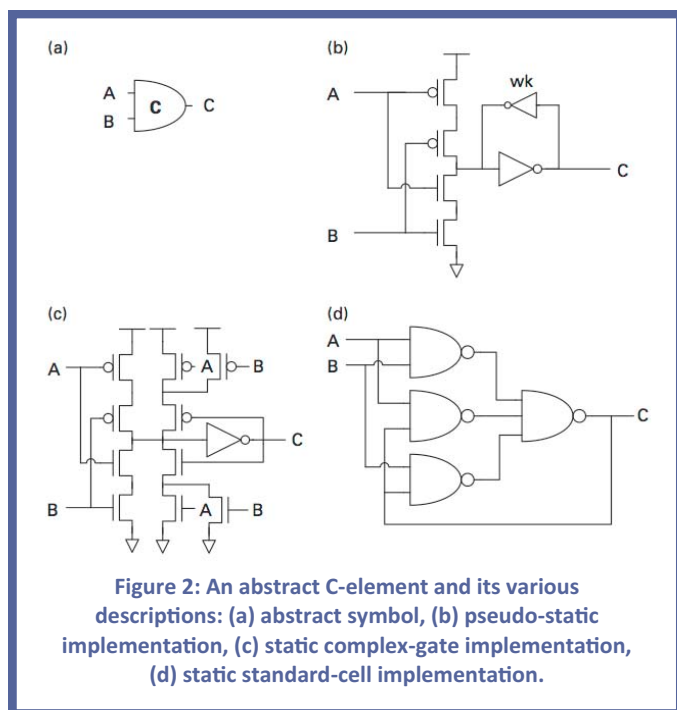


Figure 1: A simple completion-sensing tree for 3 signals.



technology (Figure 2). Regardless of implementation, each unit C-Element always requires at least one local feedback for hysteresis.

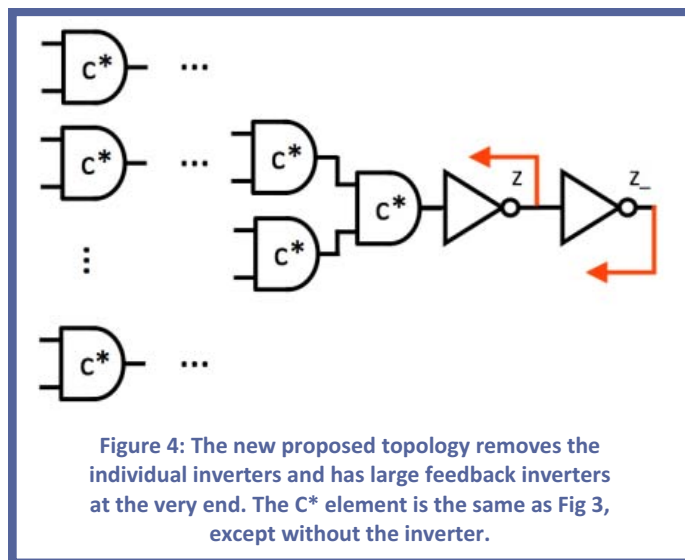
Issues arise when these elements are stacked into completion-sensing trees. Because each C element always has feedback returning for hysteresis, larger completion-sensing trees can cause additional overhead because the sum of inverter delays is proportional to the number of stages (about 4 inverter delays for 16-bit tree, 5 inverter delays for 32-bit tree).

This problem echos one of the main disadvantages of

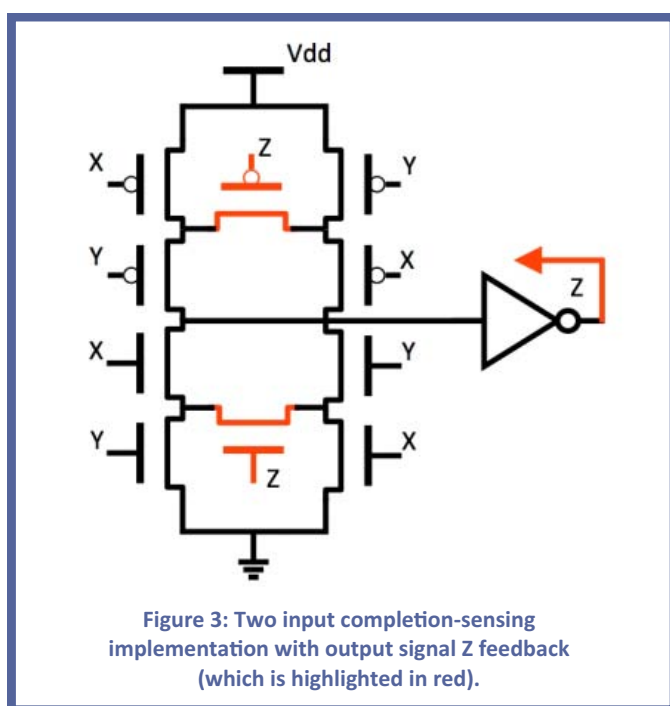
asynchronous circuit design that deter widespread adoption over synchronous digital design. The issue of completion detection caused by the large number of circuit elements can cause large overhead delays in computation and limits performance speed [4]. The more complex an asynchronous circuit is, the bigger the completion detection circuits need to be [5]. Thus any improvement in the delay performance and layout size of these trees would have a wide reaching impact in many aspects of asynchronous VLSI design [4].

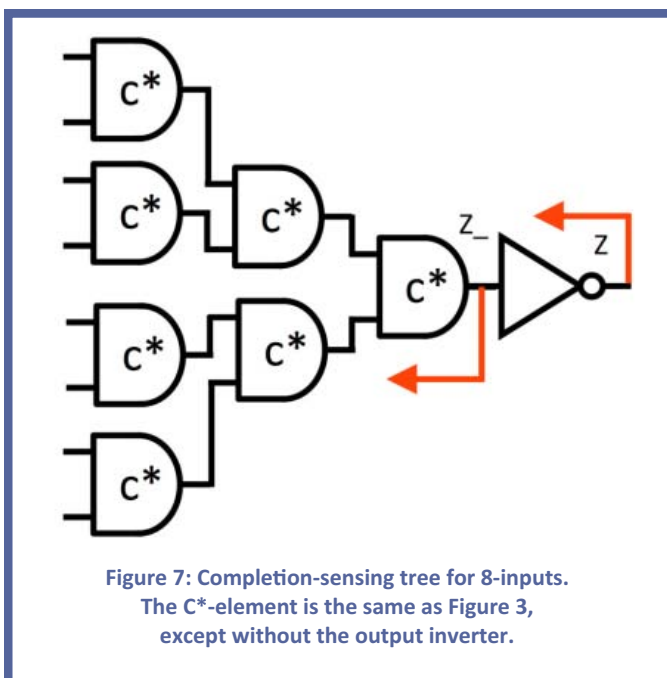
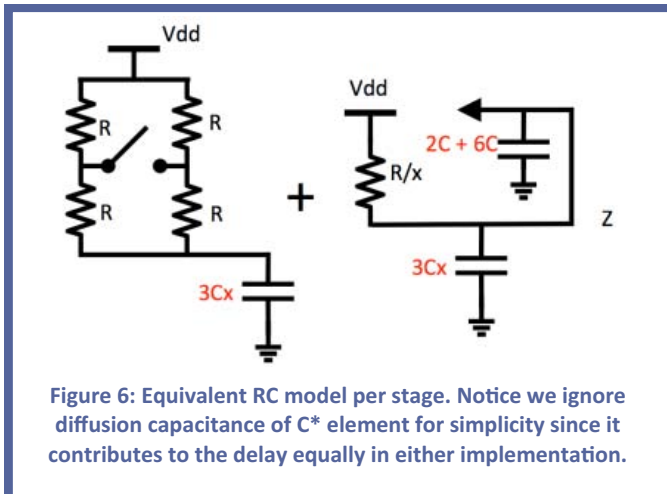
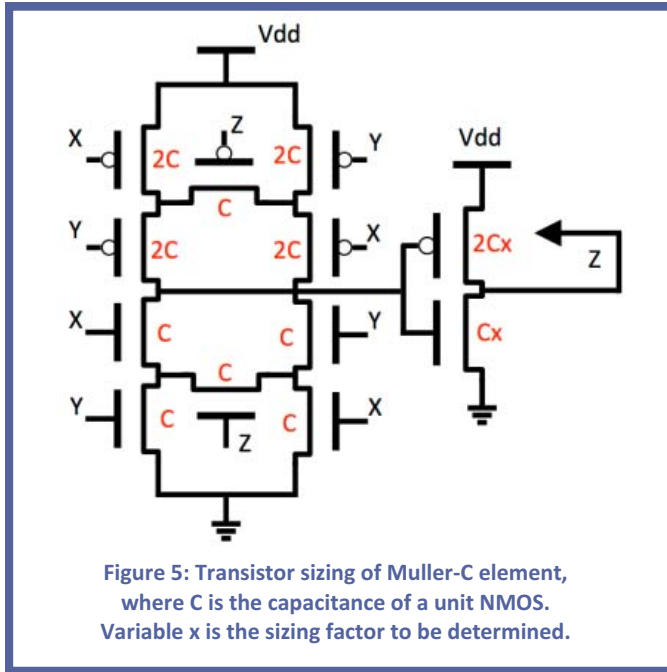
In this paper, we will focus on a specific C-element implementation for logic families of 1-of-N (Figure 3) and propose a new topological approach for stacking these C-elements into trees that reduces delay. This new approach involves consolidating the hysteresis feedback, with the goal of improving performance and reducing layout area.

While stacking C-elements to create a logic equivalent of an "N" input C-element is convenient, the inverter local to each C-element (Figure 3) is redundant since its value (which reflects the previous state value) does not hold any information about whether other inputs of the tree are valid. Instead we propose a new topology where only the global state value is maintained by consolidating the feedback into the final output of the stages (Figure 4).



By having the sole inverters at the output, there are potentially two advantages over the traditional static completion-sensing tree. First this configuration may exhibit less delay overall than stacking the individual inverter delays from each C-element because the feedback is completely consolidated. Second, delay minimization inevitably requires the inverters at the output to be much larger than those of the traditional completion-sensing trees [6]. Thus in the event of optimizing the circuit for driving larger fan-outs, the output inverters of the proposed topology could be greatly advantageous.





Delay Estimations

To gain insight into the proposed implementation, it is often helpful to use rough calculation calculations with simplified assumptions. To investigate the comparative delays of the two topologies, we used simple RC delay models, with absence of output load normalized to unit inverter delays. For the reference implementation (Figure 3), we sized the C element transistors such that the pull-up and pull-down strength were matched (Figure 5).

We then used the simple Elmore RC model and assumed that the diffusion capacitance were the same as the gate capacitance (Figure 6) [6].

Summing all sources of delays, the only degree of freedom was the sizing factor 'x' which was chosen to for minimized delay.

$$\tau_{old} = 3RCx + \frac{R}{x}(3Cx + 2C + 6C) = 3RCx + 3RC + \frac{8C}{x}, \quad (2)$$

$$\rightarrow x \approx 1.63 \rightarrow \tau_{delay} \approx 12.8 RC$$

Thus for a single C-element, we estimated a normalized delay of around 12.8 RC per stage (2). For multiple stacks of this C-element, the estimated RC delay should scale linearly with integer multiples of 12.8 RC.

For the calculations of the new topology (the C* element), we used this same calculation method for trees with size 8, 16, and 32 bits.

The completion-sensing tree for 8-input was a simple stacking of 7 C*-elements (Figure 7).

The 8-bit delay estimation was done by also optimizing the sizing factor 'x' for smaller overall delay (Figure 8).

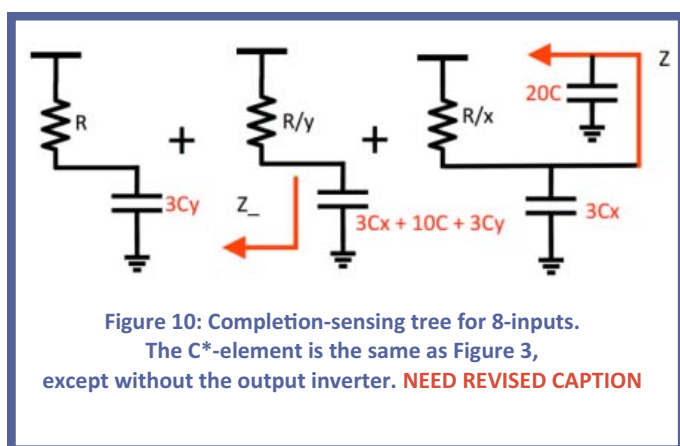
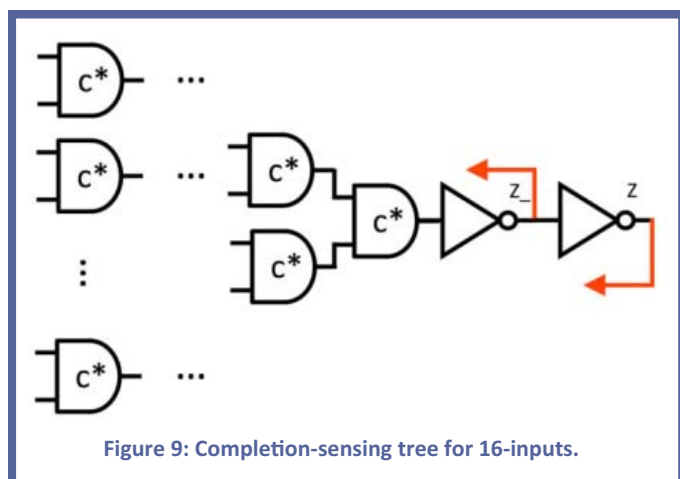
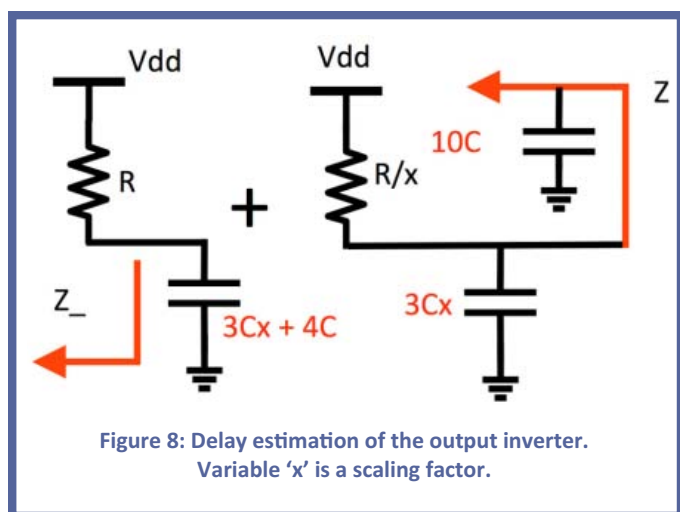
$$\begin{aligned} \rightarrow \tau_{8-new} &= \left(R(3Cx + 4C) + \frac{R}{x}(3Cx + 10C) \right) \\ &\quad + 3 \text{ stages} \times 6C \\ &= 3RCx + 25RC + \frac{10RC}{x} \\ &\approx 35.9 RC, x = 1.82 \end{aligned} \quad (3)$$

$$\rightarrow \tau_{8-old} = 3 \text{ stages} \times 12.8 RC = 38.4 RC$$

The estimates pointed to only 6% improvement (3).

$$\begin{aligned} \rightarrow \tau_{16-new} &= \left(R(3Cy) + \frac{R}{y}(3Cx + 10C + 3Cy) + \frac{R}{x}(3Cx + 20C) \right) \\ &\quad + 4 \text{ stages} \times 6C \\ &= 3RCy + 3 \frac{RCx}{y} + \frac{10RC}{y} + \frac{20RC}{x} + 30RC \\ &\approx 51.22 RC, x = 4.29, y = 2.76 \end{aligned} \quad (3)$$

$$\rightarrow \tau_{16-old} = 4 \text{ stages} \times 12.8 RC = 51.2 RC$$



expected, without explicit calculation, that the traditional topology would perform better.

In application, however, the limit of the new completion tree topology can be beyond that of the previous calculations if there are fan-out loads at the output. While the traditional topology would require additional inverters to provide the proper driving strength for a given number of fan-outs, the new topology inherently had a much higher load-driving capability.

Simulations with Predictive Models

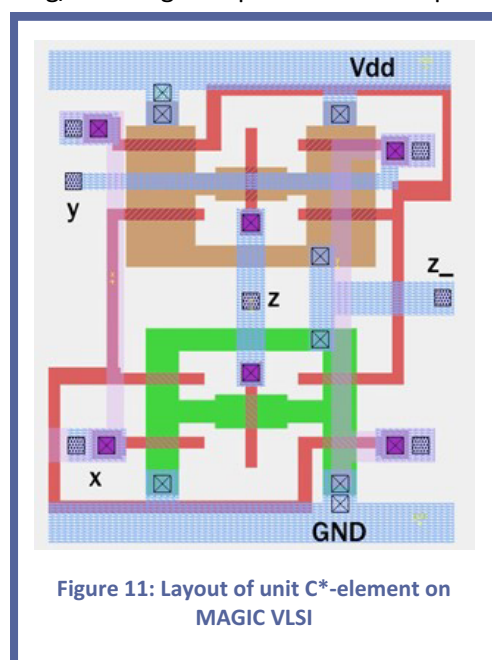
To confirm the theoretical results, simulations on HSPICE were used to test various implementations of the completion-sensing tree. The predictive technology models that were used include 40nm and 22nm metal gate technologies with the logic layout done using MAGIC VLSI.

The layout for the C*-element was done using MAGIC VLSI, with 120 nm by 40 nm NMOS and 250 nm by 40 nm PMOS gates (Figure 11).

A benchmark set of layouts were made using the traditional Muller-C element implementation of the 4, 8, 16, 32 input completion-sensing tree. Each tree was also placed under various loads. The layouts were then extracted, converted into SPICE files, and subsequently tested using HSPICE.

A set of layouts were also made using the new topology implementation of the 4, 8, 16, 32 input completion-sensing tree. Each tree was also placed under the same output loads and subsequently tested using HSPICE.

Rise and fall delays for each N input tree were tested by simultaneously raising/lowering all inputs with no output load. Further tests were done by cascading inputs to better mimic how typical asynchronous signals arrive. This involved measuring the same delays except by setting the first N-1 inputs valid before the last Nth input under various loads.



The 16-input completion-sensing tree delay was estimated with a two variable minimization (Fig. 9).

The estimations for the 16-bit input showed almost no difference in implementations. This decrease can be explained when we considered the addition of a stage of Muller-C elements from 8-inputs to 16-inputs. The delay of the traditional completion tree had roughly a linear relationship to the number of stages, while the new topology the relationship was roughly exponential. Thus for the 32-input new topology completion tree, we

Fall time (picoseconds)				
Bits	4	8	16	32
Benchmark	48.29	77.96	110.71	147.3
New Topology	38.03	81.04	115.1	164.59
Δ Percent %	21.25%	-3.94%	-3.97%	-11.74%
Rise time (picoseconds)				
Bits	4	8	16	32
Benchmark	42.84	73.42	99.16	133.53
New Topology	37.46	71.32	106.66	153.66
Δ Percent %	12.56%	2.85%	-7.56%	-15.08%

Table 1: Results from single raising or lowering all N inputs simultaneously comparing the benchmark to the new topology. Both transition times and percentage improvement are given.

Fall time (picoseconds)				
Load (Unit Inverters)	2	5	10	15
Benchmark	156.68	189.72	195.00	201.69
New Topology	158.42	158.42	158.42	160.48
Δ Percent %	-1.10%	19.76%	23.09%	27.31%
Rise time (picoseconds)				
Load (Unit Inverters)	2	5	10	15
Benchmark	177.04	209.43	217.29	221.35
New Topology	144.32	144.32	144.32	143.41
Δ Percent %	22.67%	45.11%	50.55%	53.37%
Overall %	+9.27%	+24.15%	+26.56%	+28.16%

Table 2: Results from raising/lowering 32-1 inputs before the last input for 32-bit completion trees using the new and benchmark topology. Both transition times and percentage improvement are given.

Results

The rise and fall times were collected for both the benchmark and new topology for single transitions with no output load.

As anticipated, the zero load transition delays for the new topology implementation of the completion tree become notably higher than that of the old topology for 16 inputs (4 stages) and more. For example, the fall time delay percentage difference between 8 and 16 inputs are quite close to that of the predicted RC delay (Table 1). Also notice that, as anticipated, the 32 input completion tree is the tipping point where the advantages of our new topology are gone. Thus we can reasonably expect any inputs more than 32-input (e.g. 5 stages) will have even worse delay.

Measurements were also made by fixing the number of

bits and varying the output load. The results for the 32 input implementations with various unit inverter loads were gathered and plotted (Table 2, Figure 12 and Figure 13).

Notice that the advantages of the new topology (for 32 inputs) progressively becomes better as the output load is increased. In fact, a fan out load of just more than 2 unit inverters will result in overall improved delay in both fall and rise time for the new topology.

Conclusion

Through simple relative RC delay estimations and layout simulation, the proposed new completion-sensing tree implementation was found to be advantageous in the following applications.

- Completion-sensing trees of the new topology were

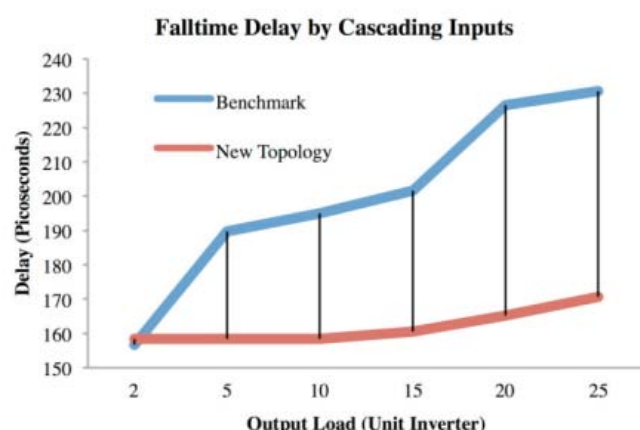


Figure 12: Comparing fall time delays in the benchmark old topology versus the new topology. The lower the delay, the better.

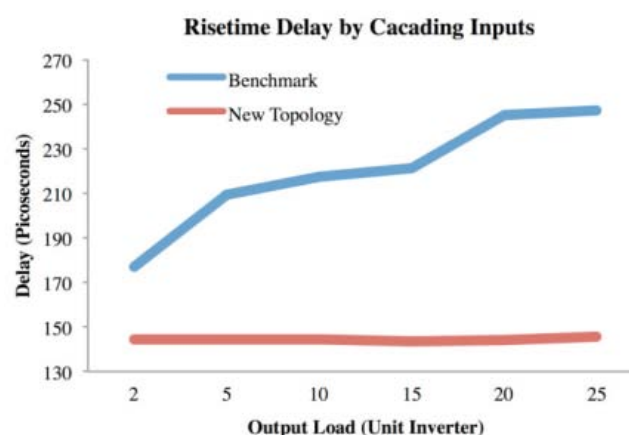


Figure 13: Comparing rise time delays in the benchmark old topology versus the new topology. The lower the delay, the better.

found to have better delays for 4 inputs with no fan-out when compared with that of the traditional topology.

- The new input completion-sensing tree topology has lower fall time delay when the output has fan out load of larger than 2 unit inverters.

As the number of stages increases, the new completion-sensing tree implementation will lose the delay advantage in having the single feedback at the output due to the exponential relationship between the number of stages and the feedback load.

This is in contrast to the traditional completion-sensing tree implementation, where each unit Muller-C element is directly fed back to the output for hysteresis. The delays of both implementations are shown to intersect approximately around 3 - 4 stages (2^3 - 2^4 inputs), where the delay of the new implementation starts to surpass the old implementation.

In real world applications, completion-sensing trees are usually required to drive some output load. For medium to large output loads, the new topology maintains a notably lower delay. Because of its inherent output load driving capabilities, the new topology has shown high potential in surpassing the traditional tree in reduced delay when larger fan-out loads are present.

Because of the ubiquity of completion-sensing trees in asynchronous logic design, the addition of this proposed design into asynchronous systems has the potential to further improve speed and performance.

However, further investigation should be done to evaluate whether this method of feedback consolidation is successful in other common C-element topologies. Other

issues worth further investigating are relative energy trade-off, delay comparisons using different N-input completion trees, and layout efficiency.

Acknowledgments

I would like to thank Chris Moore for developing the initial idea of the design as well as his guidance in providing valuable resources in the investigation.

References

- [1] A. J. Martin, M. Nystrom, and C. G. Wong, "Three generations of asynchronous microprocessors," *Design & Test of Computers*, IEEE, vol. 20, no. 6, pp. 9 - 17, 2003.
- [2] P. A. Beerel, R. O. Ozdag, and M. Ferretti, *A Designer's Guide to Asynchronous VLSI*, Cambridge : Cambridge University Press, 2010.
- [3] A. J. Martin and M. Nystrom, "Asynchronous Techniques for System-on-Chip Design," *Proceedings of the IEEE*, vol. 94, no. 6, pp. 1089 - 1120, 2006.
- [4] P. Molina and P. Y. K. Cheung, "A quasi delay-insensitive bus proposal for asynchronous systems," *IEEE Third International Symposium on Advanced Research in Asynchronous Circuits and Systems*, April 1997, Eindhoven, pp. 126 - 139.
- [5] T.-Y. Wu and S. Vrudhula, "A design of a fast and area efficient multi-input Muller C-element," *IEEE Transactions on Very Large Scale Integration (VLSI) Systems*, vol. 1, no. 2, pp. 215 - 219, 1993.
- [6] N. Weste and D. Harris, *CMOS VLSI Design: A Circuits and Systems Perspective*, Addison-Wesley, 2010.

How Work Was Done

This investigation was done as an extracurricular and independent research project in Prof. Alain Martin's Asynchronous VLSI group at Caltech from January 2013 to April 2013.

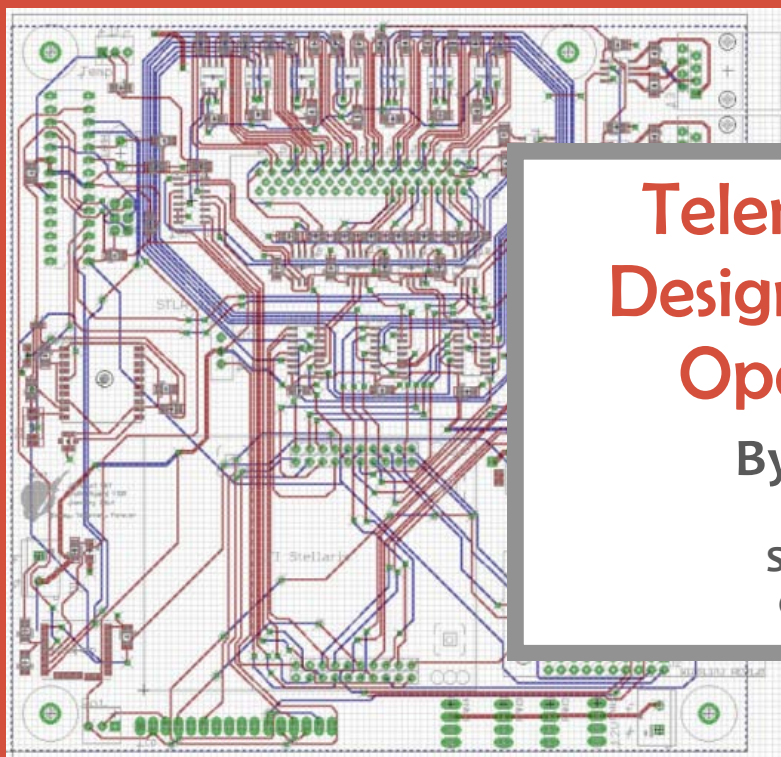
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Telemetry Processor Design for a Remotely Operated Vehicle

By Keenan Johnson
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Gamma Theta Chapter

Abstract

The Mars Rover Design Team at Missouri University of Science and Technology developed a multifunctional rover for the Mars Society's University Rover Challenge. The main processor of the rover, called the motherboard, controls various rover subsystems based on commands received from a base station, acquires data from these subsystems, collects primary location and environmental data, and transmits information to the base station. The methodology and technical design of the processor hardware and software will be described in the overall context of the collaborative team development. The paper will also discuss the process, challenges and outcomes of working with limited resources on a student design team.

Introduction

The Mars Rover Design Team (MRDT) was created at the Missouri University of Science and Technology to compete in the University Rover Challenge (URC) [1]. The URC, which has been hosted annually by the Mars Society since 2007, tasks student teams with designing and building the next generation of Mars Rovers that are capable of being operated remotely by future astronauts on Mars. This robotics competition requires a multifunctional rover vehicle that can handle specific tasks in the harsh desert environment of Utah. The Mars Society is a proponent of space exploration, in particular those activities that support the exploration of Mars.

The MRDT consists of over forty students from fourteen disciplines. The technical development involves all aspects of a custom rover-type vehicle – mechanical, powertrain, control, and communication systems. This paper describes the competition tasks, team organization, and design of the main processor. The rover processor controls various subsystems, collects required data, and communicates with the base station.

Competition Overview

The location of the 2014 competition was the Mars Desert Research Station in southern Utah, U.S.A. The rovers were stand-alone, off-the-grid, mobile platforms that are controlled via a base station. Various constraints were specified regarding budget, mass, propulsion, telemetry, etc. Rovers competing in the competition needed to complete four distinct tasks:

⇒ Sample Return Task

- The rover needed to be capable of both identifying sites of potential biological interest as well as obtaining samples from 5 cm below the surface of these sites. The Rover then had to perform an in-situation experiment on these samples which extrapolates data that is indicative of life.

⇒ Astronaut Assistance Task

- The rover needed to be capable of collecting and moving multiple objects weighing in excess of 5kg to designated GPS coordinates.

⇒ Equipment Servicing Task

- The rover needed to be capable of opening and closing valves, actuating switches and connecting threaded pipe segments to simulate repairing broken equipment.

⇒ Terrain Traversing Task

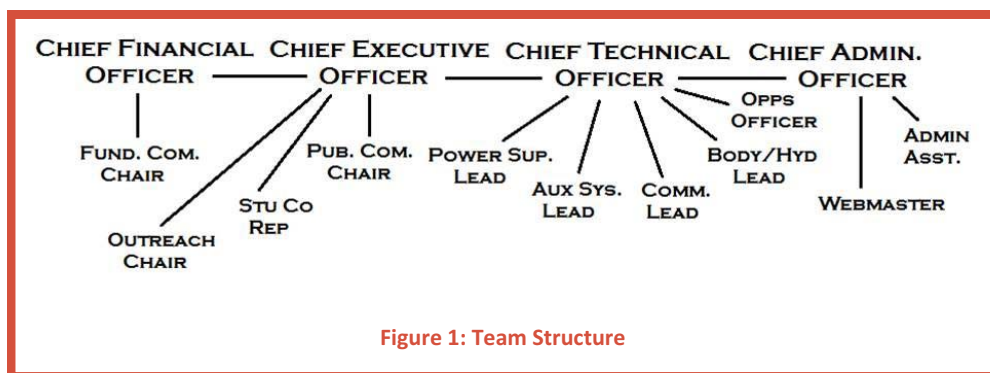
- The rover needed to be capable of traversing various terrains ranging from loose gravel to rocks with a diameter of greater than 31 cm.

The competition consisted of the rover performance of these tasks, a design presentation, and a management report.

Team Organization

The organization chart of the team is shown in Figure 1. Since the team is responsible for raising its own funding, the decision was made to structure the team much like a small business. There are four major branches of the team: The Financial, Executive, Technical, and Administrative branches. Four Executive Officers lead each branch of the team and form the core team leadership. The Financial branch is responsible for raising, managing and spending all of the money in the team. The Executive branch is responsible for the direction, outreach and vision of the team. The Technical branch is responsible for designing and constructing the Rover. Finally, the Administrative branch is responsible for the logistics of running the team.

In the technical branch, the MRDT created four Sub Teams which are responsible for the electrical, mechanical, and various other aspects of the rover. These Sub Teams - Mechanical

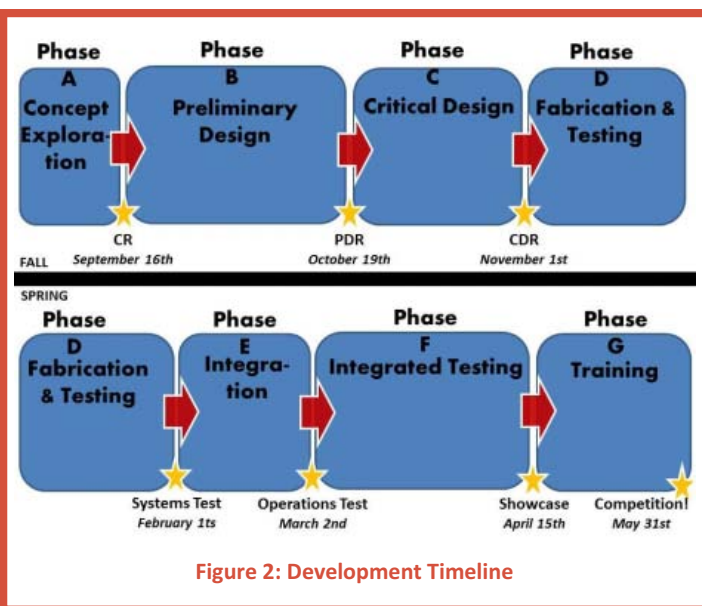


Systems, Auxiliary Systems, Telemetry and Controls, and Powertrain, respectively – have each identified the necessary designs to complete the aforementioned tasks. In addition to the interrelation of the technical design of each major system, the overall project had budget constraints. Design approaches were determined by both technical and financial considerations. The development timeline was laid out over two semesters with key dates identified for design reviews and tests as shown in Figure 2. A concept review (CR), a preliminary design review (PDR), and a critical design review (CDR) are patterned according to NASA project management requirements [3].

Technical Overview of the Electrical System

A rendering of the Missouri S&T rover is shown in Figure 3.

The rover's electrical system is summarized in Figure 4. The batteries are connected to and controlled by a battery management system which provides power to the power distribution board. This board regulates and distributes power to the rest of the rover. The motherboard is connected directly to a network switch to which the radio and cameras are also connected. The motherboard also provides power to the fans that cool the electronics enclosure. Finally, the motherboard sends control signals to the rest of the devices pictured: the camera pan, tilt, zoom (P.T.Z.) controller, a spectroscopy experiment, the robotic arm, a drill, a gripper, and the six motor controllers.



Most of the components shown in Figure 4 were designed and manufactured by the team. After evaluating several commercial options the team could not find a system within the budget that would provide them with the required features. Thus, many of the components were designed and manufactured in house. The motherboard is a custom printed circuit board that sits at the center of the rover's electrical system. All control signals and telemetry for the rover pass through the motherboard.

Specifications

The motherboard had three primary purposes:

- To aggregate and transmit data from the rover subsystems to the base station
- To receive control commands from the base station, interpret them, and issue the appropriate control signals to the rest of the rover
- To house several primary sensors including a G.P.S. module

Additionally, the project needed to be easily manufacturable, while adhering to the team's schedule and budget. A custom printed circuit board was designed to accomplish the aforementioned goals. This allowed the team complete control over the functionality of the board and gave the team members valuable experience in hardware design, manufacturing and troubleshooting.

Hardware Design

Figure 5 lists the major hardware components and describes the topology of the motherboard.

At the center of the motherboard, sits an ARM M4 micro-controller that acts as the primary processor for the rover. In early iterations of the motherboard, this processor was soldered directly to the motherboard. However, the pitch of the processor pins proved to be too small for the team to reliably manufacture. To circumvent this problem, the team chose to utilize the Texas Instrument LM4F120 LaunchPad Evaluation Board as the main processor. This development board has female header pins on the bottom of the board. This allowed the team to place easy-

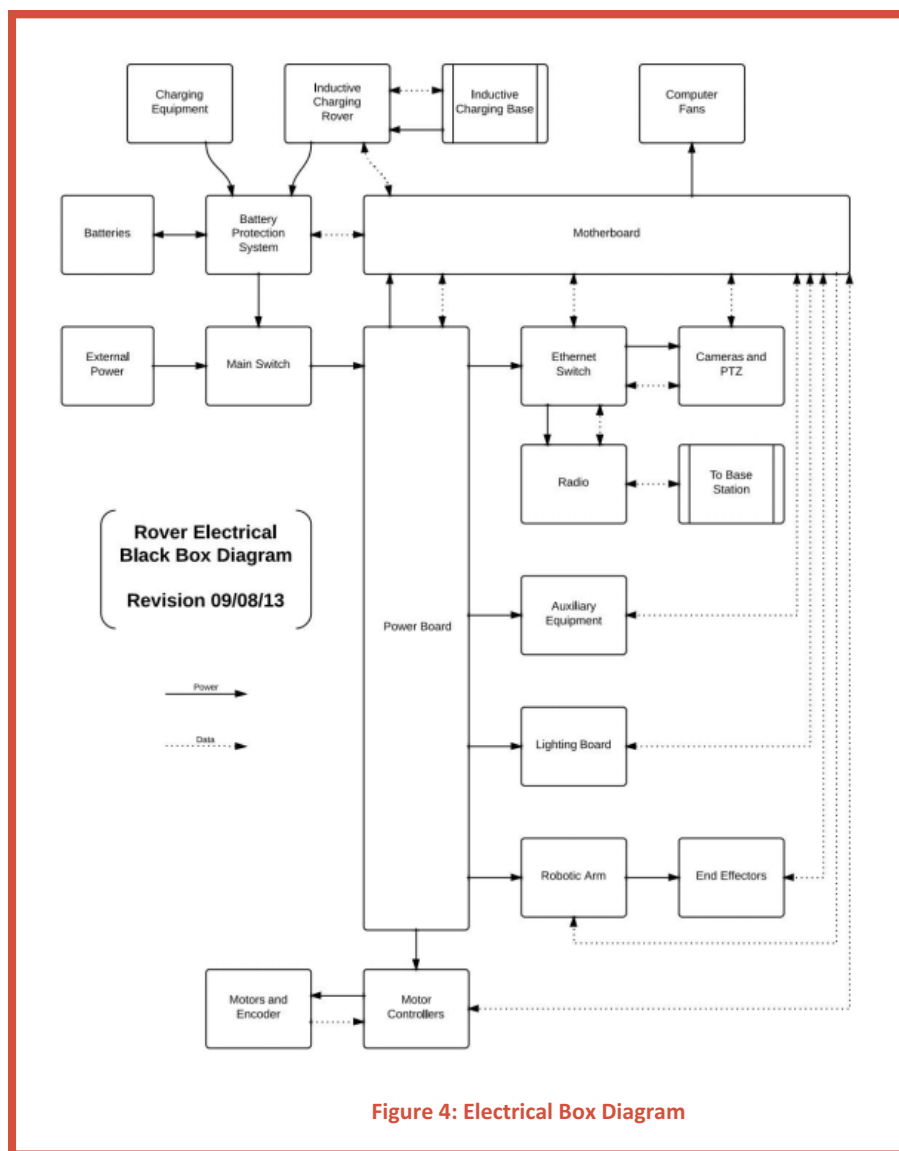


Figure 4: Electrical Box Diagram

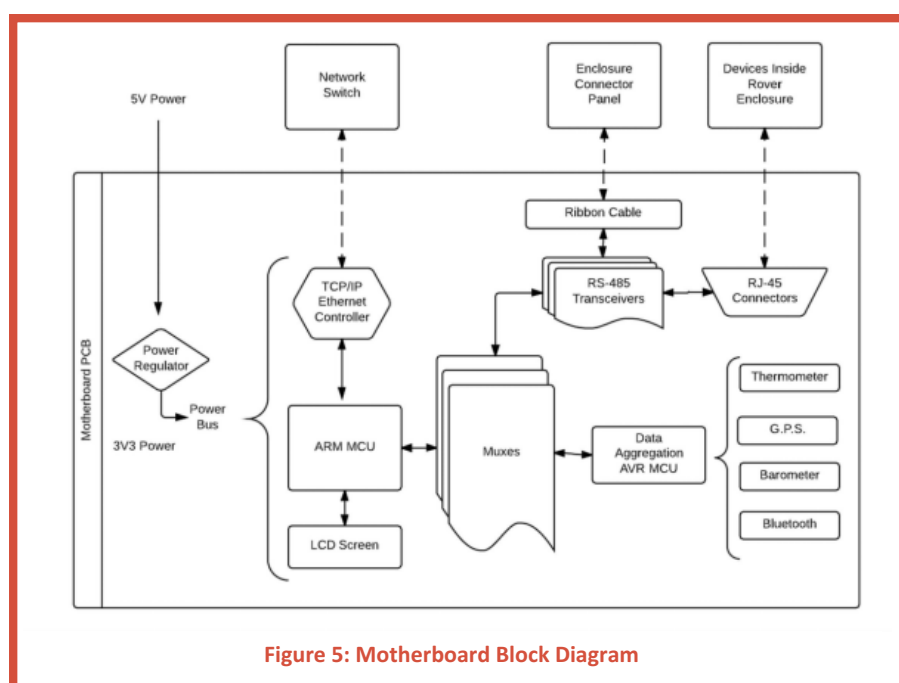


Figure 5: Motherboard Block Diagram

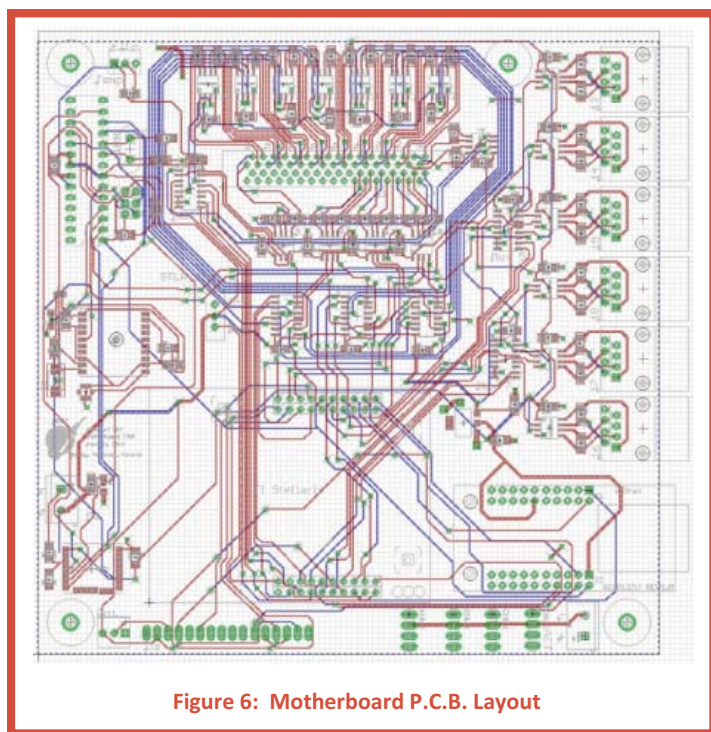


Figure 6: Motherboard P.C.B. Layout

to-solder male header pins on the printed circuit board and simply insert the entire Launchpad board onto the motherboard. This method had the added advantage of allowing the team to remove the Launchpad in order to program, flash and debug the main processor without requiring the rest of the motherboard. The circuit board layout is shown in Figure 6.

The link to the base station comes from a TCP / IP controller chip, the Wiznet 5100. This chip was mounted in the same way as the Launchpad, using the breakout headers since the pitch was also very small. All communication with the base station came through this path, flowing first through this chip, then through a network switch on board the rover and finally out of the 2.4 GHz radio.

A secondary micro-controller on the motherboard was used to manage and aggregate data from several sensors on the motherboard, thus relieving the primary processor of the low level collection and management tasks. This processor was an Atmel ATmega328P. The team used this processor for all onboard computing tasks, with the exception of the main TI processor. This allowed the team to make use of the easy to use and learn libraries provided as part of the Arduino environment. The common processor also allowed the team to minimize the number of spare parts required.

This auxiliary processor is directly connected to a G.P.S. receiver, temperature and humidity sensors, and a Bluetooth transceiver. The team made use of both the G.P.S. receiver and the temperature / humidity sensor. However, due to time constraints, the team did not implement software for the Bluetooth transceiver.

All other electronics on the rover connect to the motherboard via RS-485 connections. This differential pair signal standard works well since it can be implemented as full duplex and utilizes off-the-shelf Ethernet cable and RJ-45 connectors. The motherboard has 20 RS-485 transceivers: 6 are connected to RJ-45 jacks mounted directly on the motherboard, 12 are connected to a ribbon cable that connects to a patch panel mounted on the exterior wall of the rover's electronics housing. The main processor on the rover contains only six accessible hardware universal asynchronous receiver / transmitter connections, while the rover needed to control 18 devices. To solve this issue, a series of dual channel multiplexers are connected between the main processor and the RS-485 transceivers.

Software Design

The team was also responsible for developing all of the software for the motherboard. This included both the main processor and the sensor co-processor. All software was written in either C or C++ and is discussed further below.

Main Processor Software

In order to create a responsive system, the team decided that they would need to use a real time operating system (RTOS) that could handle scheduling and prioritizing tasks to run on the single core of the processor. Several different options were considered including a full Linux kernel with the real time patch. In the end, the team chose a free RTOS from Texas Instruments called TI-RTOS that already has many drivers written for the LM4F120 processor. Furthermore, the RTOS comes with a preconfigure development environment and debugger. Skipping the tool-chain configuration likely saved the team a significant amount of work.

The team defined two tasks, a command processing task and a telemetry aggregation and transmission task. The command task was given a higher priority than the telemetry task and would preempt the telemetry task if a command was received. The command task had to first decode the message from the base station. It then changed the appropriate multiplexer to the correct RS-485 transceiver and sent the message in the format described below. When no commands were in the command queue, the telemetry task cycled through all devices connected, polling for the latest telemetry values. Messages to the base station were then constructed for each telemetry parameter and sent into the TCP connection to the base station.

Sensor Co-Processor

The sensor co-processor software consisted of a single, infinite loop that would execute the following sequence in order:

- Poll G.P.S. receiver for position
- Poll temperature sensor for temperate & humidity
- Send data to motherboard

Base Station Message Format

In order to support legacy base station code, JSON was required for commands to the rover and for telemetry sent to the base station. The motherboard team would have liked to use a more compact binary pack format to save time processing and constructing each JSON message onboard the rover; however, the team did not have the resources to rewrite significant portions of the base station to support a new message format. Telemetry and commands followed a common format. Each message contained an identification field and a value field as shown in Figure 7. The identification field was a four digit number that served as the key for each message. The value was either the value of the telemetry parameter or the value for the command.

Inter-Rover Message Format

Communication internal to the rover was done by serializing standard c structs. Each message contained the following

```
{
  "MessageID" : "1002",
  "Value" : "50"
}
```

Figure 7: Example Base Station Message

Start Byte 1
Start Byte 2
Size of Payload
Payload Byte 1
Payload Byte 2
Payload Byte 3
.....
Payload Byte Size
Checksum

Figure 8: Inter-rover Message Format



Figure 9: The completed rover.

components shown in Figure 8, where each row represents an eight bit byte. The two start bytes in the beginning are to ensure that the message is correctly byte aligned. The next byte, the size, indicates the number of payload bytes. The payload is the serialized struct with any padding bytes removed. Finally, a checksum is added to ensure that the data arrives intact. The software on the receiving side, will discard any messages that fail the checksum.

Design Control

The team versioned all of the hardware and software design files using the Git version control software. The repository was then published to Github, an online repository hosting site. The site also contained a wiki with documentation for all others working on the rover to quickly reference. This allowed all members of the team access to all design files at any time.

Conclusion

In the early summer of 2014, the Missouri S&T team took the rover to the Mars Desert Research Station in Utah, U.S.A. to compete in the University Rover Challenge. Figure 9 shows the rover at the competition site. The team had learned much from designing, troubleshooting and operating the rover over the course of the year. Additionally, the team learned about how to manage a large-scale project and deal with the integration issues in a timely and effective manner. The decision of whether to design and manufacture a component or to purchase one was tough, but ultimately the team made effective decisions. The decision to design a custom motherboard, as well as a multitude of other custom hardware for the rover, proved to be a

successful decision. The team encountered no major hardware or software problems with the motherboard during competition, allowing the team to place second. This verifies that it is indeed possible for a group of volunteer students to design, fabricate, and program a custom motherboard that interoperates well in a complex, successful, multi-system rover. Other information on the telemetry and control can be found in the references [3].

How Work Was Done and Acknowledgments

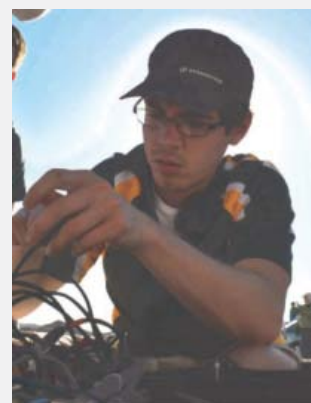
The Missouri University of Science & Technology's 2014 Mars Rover was designed, and constructed entirely by current students at the University. The effort was organized as a formal Design Team and operates in the campus Student Design and Experiential Learning Center (<http://design.mst.edu/teams/>). The author thanks Dr. Kurt Kosbar for serving as technical advisor for the technical work described in this paper.

References

- [1] University Rover Challenge, (2014) <http://urc.marssociety.org/>.
- [2] Randal L. Taylor, Reducing NPR 7120.5D to Practice: Preparing for a Remote Site Life-cycle Review," 2009 IEEE Aerospace Conference, Big Sky. Montana, March 2009.
- [3] Tyler Morrow, "A Modular and Extensible User Interface for the Telemetry and Control of a Remotely Operated Vehicle," International Telemetry Conference, San Diego, California, October 2014.

About the Author:

Keenan Johnson, from Jefferson City, Mo, currently studies Computer Engineering with a minor in Computer Science at Missouri University of Science & Technology. In addition to his active involvement in IEEE-HKN, Keenan is active on several student design teams. He previously served as President for Miners In Space Student Design Team and led them in designing and conducting research on C.P.R. in micro-gravity aboard N.A.S.A.'s "Weightless Wonder" aircraft. He currently serves as a technical lead for Missouri S&T's Mars Rover Team Motherboard Squad.





GazePointer: Computer Vision Based Eye Gaze Tracking for Human-Computer Interaction

By Muhammad Usman Ghani and
Muhammad Adnan Siddique
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Abstract

Human-Computer Interaction (HCI) researchers have been working on the development of new interaction techniques. As an alternative to touch based computer interfaces, HCI research has investigated eye gaze as a means of interaction. It is proposed that eye gaze can offer direct means of interaction, since it avoids the involvement of a hardware mouse, hand gestures or finger touch. This paper endeavors to demonstrate a low-cost real-time computer vision based eye gaze tracking algorithm developed for HCI applications.

Introduction

Researchers are working to develop innovative and efficient interaction techniques for computer users, e.g. Human-Computer Interaction (HCI). One alternative to touch-based interaction is eye gaze tracking [1]. Human eye movements carry a significant amount of information, especially as related to the person's point of interest. This information can be extracted and manipulated for use in applications such as HCI. If the computing device can detect eye gaze of the interacting person, little further intervention is required to interact with the machine. The mouse pointer automatically follows the person's point of interest. An eye gaze tracking based HCI technique could speed up the interaction processes.

Researchers have been working on conducting studies about eye gaze tracking and developing systems capable of eye gaze based interaction. Many companies have developed proprietary solutions and have made them available in the market; but these solutions offer limited usability, involve complex hardware, do not provide user-friendly human-computer interaction, and are very costly; which make them out of reach for domestic users.

GazePointer investigates the potential of eye gaze in HCI applications. A computer vision based tracking algorithm was developed using eye gaze that can provide low-cost, real-time human-computer interaction. The idea behind GazePointer was to develop an interface that can enhance user experience of interaction. A person's point of gaze was tracked using a webcam system and controlled mouse pointer movements accordingly. This paper reports related literature, overviews the system and its implications, describes the Eye Gaze Tracking algorithm, and discusses experimental results and future research.

Literature Review

Several research studies have been conducted on eye gaze tracking technique; applying various approaches to achieve gaze tracking. An eye gaze tracking approach

based on Electro-Oculography (EOG) takes advantage of the electrostatic field that exists around eyes and varies with eye-ball movements. These minor variations can be captured by placing electrodes around eyes. The technique becomes cumbersome due to usage of electrodes and is not suited well for everyday usage. Such an application is presented in [2], and a detailed review of EOG based techniques is demonstrated in [3].

Contact lens tracking based techniques have been developed and offer satisfying performance but they are uncomfortable and invasive. A lens based tracking technique is discussed in [4]. Head-mounted eye gaze tracking techniques are also proposed, but they are not friendly for general purpose use. Head-mounted tracking approaches have been explored in [5, 6].

Video-based techniques can also be applied for eye gaze tracking, but computing devices with low processing capacities restricted video-based solutions. Advent of machines with high processing power has made it possible to provide real-time interaction using video-based techniques. Various video-based tracking approaches has been proposed recently. Purkinje Image Tracking [7] and Corneal Reflections [8] are examples of such systems. This paper presents a low-cost, real-time interaction technique using computer vision algorithms.

System Description and Significance

This research work attempts to address the very complex problem of eye gaze tracking, using basic and simplified algorithms, in order to make it low-cost, user-friendly and real-time. The problem statement of the study was defined as “design and implement a simplified technique using computer vision algorithms to provide low-cost and real-time human-computer interaction based on eye gaze tracking that will only require a computing device and a web-cam”. This study also suggests that eye gaze has the potential of offering an efficient means of interaction and could be especially useful for handicapped people.

The approach could have wide applications; eye gaze tracking has potential applications ranging from home appliances control to aviation, from neurosciences to intelligent tutoring systems, and from Psychology to advertising. The proposed technique offers non-invasive

gaze-tracking and uses a software only approach. The proposed system requires only a computing device and makes use of built-in web-cam which captures image frames. Images are processed through GazePointer and provide smooth, real-time interaction after detecting point of gaze.

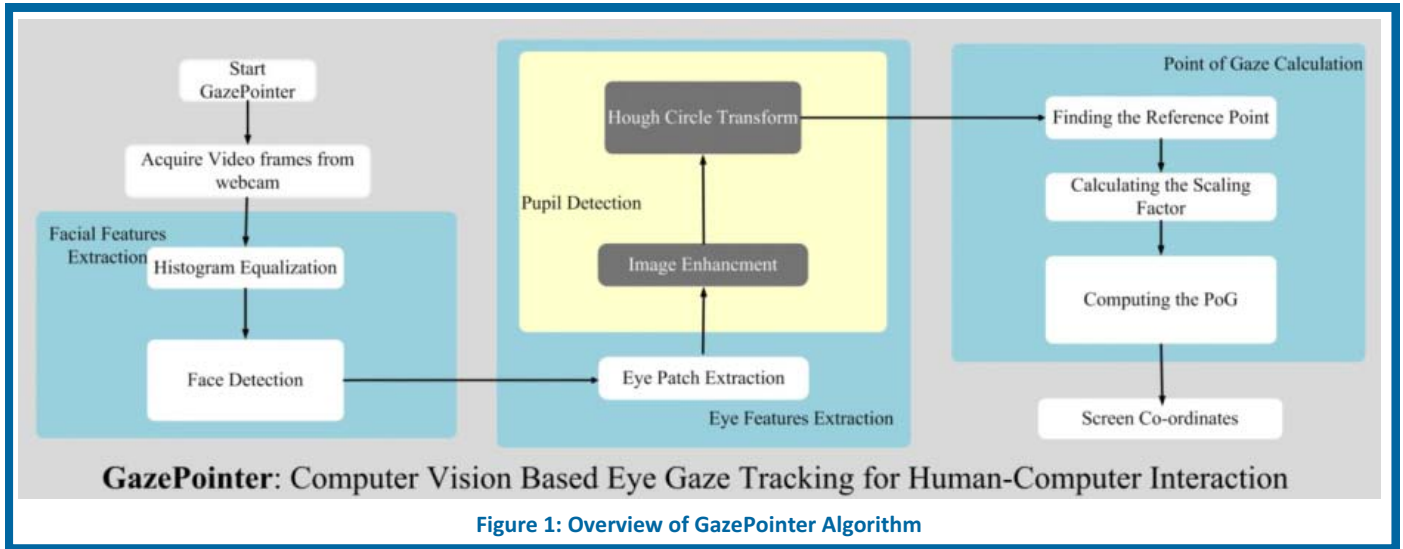
Eye Gaze Tracking Algorithm

The GazePointer tracking algorithm is briefly illustrated in Figure 1. The algorithm has three main components: facial features extraction, eye features computation, and point of gaze calculation. The algorithm processes grayscale images only, therefore, image color space conversion may be performed, if required. The histogram of grayscale images is then equalized [9] for contrast normalization. A face detection technique based on Viola and Jones’ object detection algorithm [10] is then applied to detect the face in an acquired image. Eye features are then computed by Viola and Jones’ object detection algorithm [10] for eye patch extraction.

Eye patch extraction and face detection require a complex process involving much computation. In order to make GazePointer work in real time, initial frames are firstly down sampled and then face and eye patch co-ordinates are mapped to the original image after face and eye patch extraction. This procedure drastically improved the computational efficiency of the proposed algorithm.

Gaze tracking is a complicated problem, in which a sufficient number of facial and eyes features must be computed and fed to the Point of Gaze (PoG) computation method. After a thorough analysis and study, two most important features were identified, pupil and eye corners. The pupil being the focusing and central part of the eye gives cues about the user’s point of interest. Eye corners are also important to identify as they give information about the area of eye being used to trace the Test Area.

The extracted eye patch is further processed before pupil detection with a smoothing filter. This is done to reduce false positives for pupil detection. Hough Circle Transform (HCT) [11] is then applied to detect the pupil. HCT is applied on a digitized version of the extracted eye patch, using a canny edge detector [12]. It was observed that the complete area of eye is not used to trace the Test Area;



therefore, a simple calibration technique was developed to compute that region of eye.

PoG denotes the user's point of interest in the Test Area. The PoG computation algorithm takes detected features and outputs the user's Point of Gaze in the Test Area with respect to a reference point. Four corner points were already computed during the calibration stage; a simple average of these corner points output 'Center of Eye'. The 'Center of Eye' is computed using Equation 1 and Equation 2 and it is taken as reference point.

$$COE_x = \frac{(TopRightCorner_x + TopLeftCorner_x)}{2} \quad (1)$$

$$COE_y = \frac{(TopRightCorner_y + BottomRightCorner_y)}{2} \quad (2)$$

Here, COE_x and COE_y represent x and y co-ordinates of Center of Eye respectively. $TopRightCorner_x$, $TopRightCorner_y$, $TopLeftCorner_x$ and $BottomRightCorner_y$ form movable region of eyes that trace Test Area. The next step requires estimation of scaling factor, which would be applied to pupil movements in order to translate pupil movements into GazePointer movements in Test Area. It needs height (h_{eye}) and width (w_{eye}) of eye's area used to trace Test Area, these can be computed using Equation 3 and Equation 4. X (R_x) and Y (R_y) co-ordinates of Scaling factor can be computed using Equation 5 and Equation 6. Here, h_{screen} and w_{screen} represent height and width of Test Area.

$$w_{eye} = TopLeftCorner_x - TopRightCorner_x \quad (3)$$

$$h_{eye} = TopRightCorner_y - BottomRightCorner_y \quad (4)$$

$$R_x = \frac{w_{screen}}{w_{eye}} \quad (5)$$

$$R_y = \frac{h_{screen}}{h_{eye}} \quad (6)$$

PoG computation takes advantage of reference point 'Center of Eye', it computes the displacement of pupil from COE and translates these pupil movements in eyes into GazePointer movements in Test Area. PoG translation can be performed using Equation 7 and Equation 8.

$$PoG_x = \frac{w_{screen}}{2} + R_x \times r_x \quad (7)$$

$$PoG_y = \frac{h_{screen}}{2} + R_y \times r_y \quad (8)$$

Here, PoG_x and PoG_y denote x and y co-ordinates of PoG; r_x and r_y represent x and y co-ordinates of pupil displacement in eye (from reference point). r_x and r_y can be calculated by applying Equation 9 and Equation 10.

$$r_x = COI_x - COE_x \quad (9)$$

$$r_y = COI_y - COE_y \quad (10)$$

Here COI denotes pupil position. This concept is illustrated in Figure 2. A simple four-point calibration mechanism is developed. It is used to estimate the region of eye being used to trace the 'Test Area'. It suggests the user to gaze at all corners of 'Test

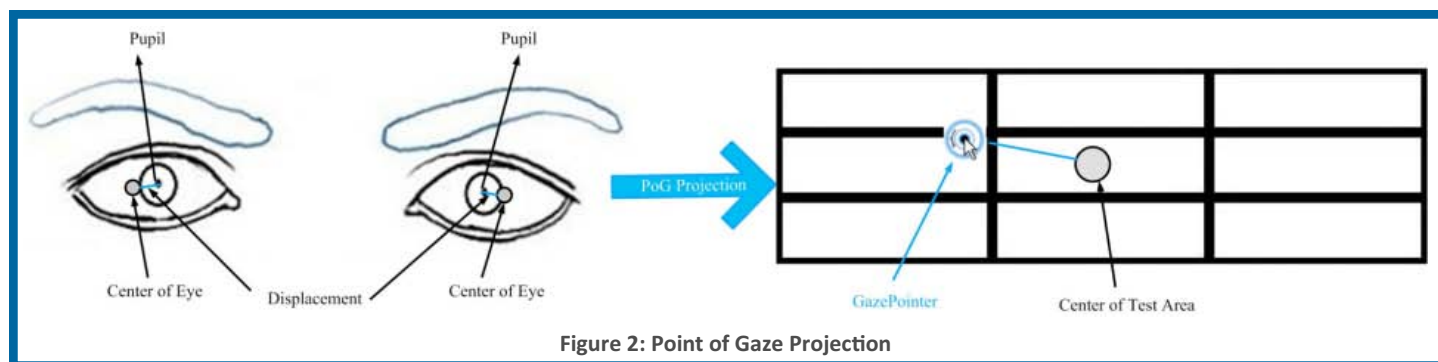


Figure 2: Point of Gaze Projection

Area' one by one, for an arbitrary amount of time. Achieved information is further used in PoG calculation algorithm, as described earlier.

Experiment Results

Two experiments have been designed to test the developed algorithms. The first test uses the algorithm in a live real-world environment and the second test uses a simulated environment. Experiments testing was performed on Intel® Core i3 HP Probook 4530s, it has a built-in web-cam with 720p resolution which was used as the image capturing device.

Experiment 1: GazePointer GUI

Experiment 1 is designed for real-world environment testing of the proposed algorithms. In order to compute accuracy, achieved results are recorded into a video file and later all recorded frames are manually analyzed. If face and eye patch are detected in a frame, rectangular boxes are drawn around detected face and eye patch by system. If the iris and pupil are found, circles are drawn around them by system. During analysis of recorded frames, the detection is considered correct if the drawn rectangle or circle appears within a distance of 1 pixel from the exact location. Otherwise, it is considered incorrect.

The achieved result for a frame is presented in Figure 3. Detailed

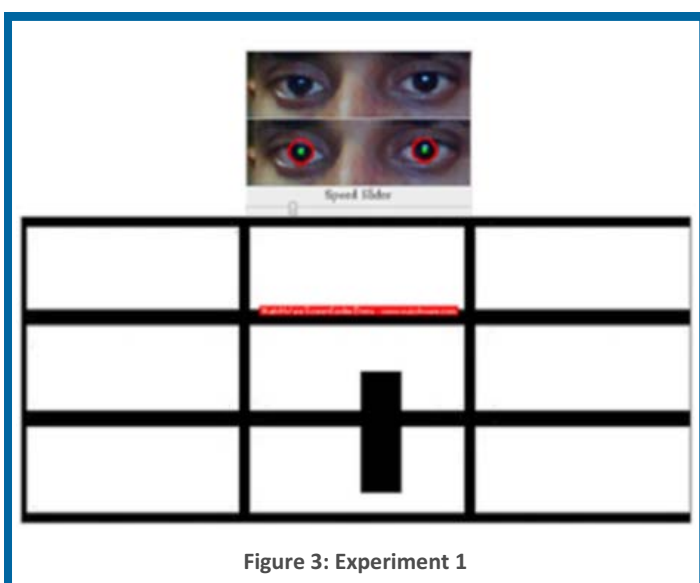


Figure 3: Experiment 1

accuracy results of experiment 1 are given in Table 1. The algorithm resulted in 87% accuracy for experiment1. Experiment1 results are being reported on 228 frames. There are a few limitations for this experiment, it was only tested for frontal faces and with a single person facing the web-cam. The distance between a user's eyes and interface was not more than 75 cm. The system was tested in good lighting environment and did not allow head movements or use of glasses.

Extracted Features	Accuracy
Face Detection	100%
Eye Patch Extraction	100%
Pupil Detection	87%

Table 1: Experiment 1 Accuracy Results

Time efficiency results for experiment 1 are given in Table 2. Overall processing time for each frame is being reported to be 31-43 ms, which provides interaction at rate of 23 fps.

Extracted Features	Processing Time (ms)
Face Detection	13-15
Eye Patch Extraction	10-15
Pupil Detection	6-10
PoG Computation	2-3

Table 2: Experiment 1 Efficiency Results

Experiment 2: Test Bench

A test bench was designed to test developed algorithms in ideal scenarios. Artificial eyes were used in this experiment. These artificial eyes are computer drawings; one drawing contains an eye patch without an iris and other contains an iris. A computer program was setup to simulate eye movements based on eye movements of actual users. The achieved results for a frame are demonstrated in Figure 4. Experiment 2 results show that system accuracy remains 100% for simulated environment, results are given in Table 3.

Extracted Features	Accuracy
Pupil Detection	100%
PoG Computation	100%

Table 3: Experiment 2 Accuracy Results

Table 4 presents processing time for all modules in experiment 2. Achieved results show that system takes 8-13 ms per frames.

Extracted Features	Processing Time (ms)
Pupil Detection	6-10
PoG Computation	2-3

Table 4: Experiment 2 Efficiency Results

Conclusion and Future Research Directions

This paper presents a low-cost, real implementation of an eye gaze tracking algorithm for HCI. Eye gaze tracking has applications in several fields. The approach applies simple and classical computer vision algorithms and demonstrated the feasibility of the approach.

The system was limited by lighting, equipment, and user variation, e.g. posture and glasses. The performance deteriorated in poor lighting conditions. The GazePointer size was also large, since the web-cam was low resolution. This can be improved with enhancement in web-cam resolution and Test Area size. Image pre-processing procedures can also be employed to improve performance in poor lighting environments. Head-posture descriptor can also be included to allow head movements. Gaze estimation can also improve system performance and particle filters can be applied to achieve gaze estimation.

Acknowledgments

The authors would like to thank Mr. Muhammad Nafees Geelani, Ms. Sarah Chaudhry and Ms. Maryam Sohail for their help in conducting experiments.

How Work Was Done

This research work was carried out as Final Year Project during undergraduate degree. It was a team based project, which included student and a supervisor from University faculty (Mr. Muhammad Adnan Siddique).

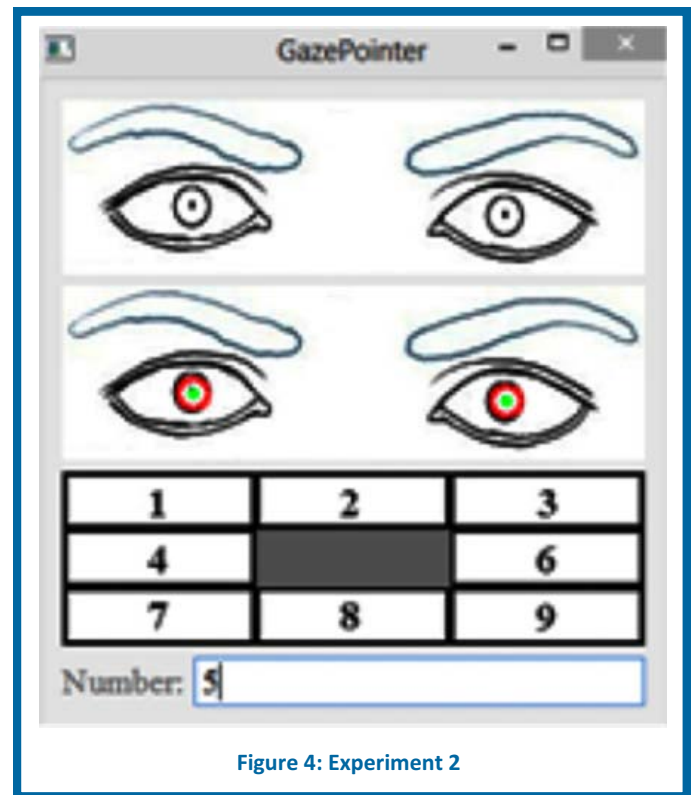


Figure 4: Experiment 2

References

- [1] M. U. Ghani, S. Chaudhry, M. Sohail and M. N. Geelani, "GazePointer: A Real Time Mouse Pointer Control Based on Eye Gaze Tracking," 16th IEEE International Multi topic Conference (INMIC) 2013, Lahore, Pakistan, 2013.
- [2] R. Barea, L. Boquete, M. Mazo and E. López, "System for assisted mobility using eye movements based on electrooculography," IEEE Transaction on Neural Systems and Rehabilitation Engineering, vol. 10, no. 4, pp. 209-217, DECEMBER 2002.
- [3] H. Singh and J. Singh, "A Review on Electrooculography," International Journal of Advanced Engineering Technology, vol. III, no. IV, 2012.
- [4] K. Irie, B. A. Wilson and R. D. Jones, "A laser-based eye-tracking system," Behavior Research Methods, Instruments, & Computers, vol. 34, no. 4, pp. 561-572, 2002.
- [5] P. Ballard and G. C. Stockman, "Computer operation via face orientation," Pattern Recognition, 1992. Vol.I. Conference A: Computer Vision and Applications, Proceedings., 11th IAPR International Conference on, 1992.
- [6] T. Horprasert, Y. Yacoob and L. S. Davis, "Computing 3D head orientation from a monocular image sequence," 25th Annual AIPR Workshop on Emerging Applications of Computer Vision, 1997.

[7] K. Arai and M. Yamaura, "Computer Input with Human Eyes-Only Using Two Purkinje Images Which Works in a Real-Time Basis without Calibration," CSC Journals, vol. 1, no. 3, pp. 71-82, 2010.

[8] D. H. Yoo, J. H. Kim, B. R. Lee and M. J. Chung, "Non-contact Eye Gaze Tracking System by Mapping of Corneal Reflections," Fifth IEEE International Conference on Automatic Face and Gesture Recognition (FGR'02), 2002.

[9] R. Gonzalez and R. Woods, Digital Image Processing, 3rd ed., Pearson Education, 2009.

[10] P. Viola and M. Jones, "Rapid Object Detection using a Boosted Cascade of Simple Features," COMPUTER VISION AND PATTERN RECOGNITION, 2001.

[11] C. Kimme, D. Ballard and J. Sklansky, "Finding circles by an array of accumulators," in Communications of the Association for Computing Machinery, 1975.

[12] J. F. Canny, "Finding edges and lines in images," M.S. thesis, Dept. Elect. Eng. Comput. Sci., Massachusetts Institute of Technology, Massachusetts, CA, 1983.

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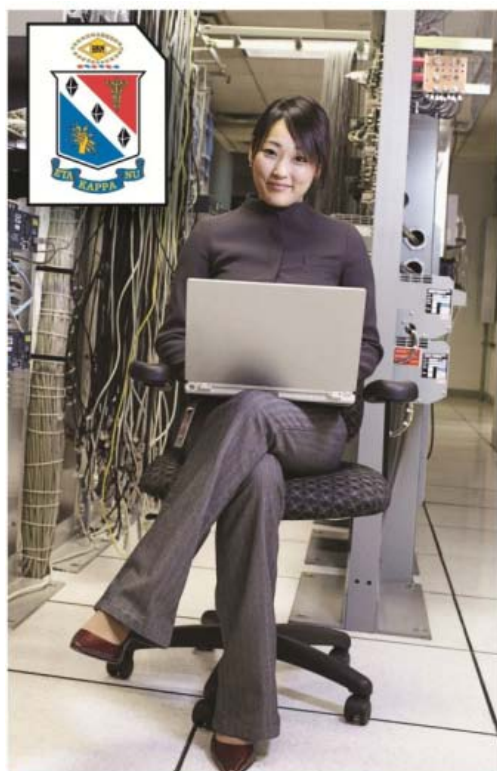
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NEWS AND UPDATES



Sections Congress Recap

IEEE Sections Congress, held every three years since 1984, provides IEEE Section leadership with a priceless opportunity to impact the future of IEEE. This past 22 to 24 August, hundreds of IEEE volunteers and staff traveled to the Rai Convention Center in Amsterdam, Netherlands, for the 2014 Sections Congress. This was the first time the event was held outside of North America.

The goals of the event, which focused on the theme of "Inspiring Our Leaders of Tomorrow," were three-fold: to provide an opportunity for delegates to gain information and training skills; to network and build relationships with other volunteers within IEEE; and to serve as a forum for Section representatives and other local leaders, enabling them to voice – on behalf of the collective membership – the ideas, issues, and recommendations which will impact the development and growth of IEEE throughout the world, reinforcing its vitality and relevance to those it serves.

Members of the IEEE Educational Activities team represented IEEE-HKN and participated in learning labs and other activities to raise awareness of the honor society. The primary goal was to demonstrate to a global audience the benefits of having an IEEE-HKN chapter on campus – to the students, to the school, to the local community and to the Sections and Regions of IEEE. IEEE-HKN is critical for the development of future leaders, both within IEEE and within the profession.

Both alumni as well as representatives of prospective new chapters visited the Educational Activities booth to connect with IEEE-HKN.



Top L-R: Dr. Jerry Hudgins, Electrical Engineering Department Chair, University of Nebraska - Lincoln (Beta Psi chapter); Dr. Mo El-Hawary, faculty adviser, Dalhousie University (Lambda Theta chapter) Governor Regions 7-10, IEEE-HKN Board of Governors.

Bottom L-R: Teófilo Ramos, Tecnológico de Monterrey (Lambda Rho chapter); Dr. Timothy Kurzweg, faculty adviser, Drexel University (Beta Alpha chapter); Governor-at-Large, IEEE-HKN Board of Governors.

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NEWS AND UPDATES



IEEE-HKN Strategic Direction Update

The Board of Governors of IEEE-HKN has approved and will implement the Strategic Initiatives as recommended by the IEEE-HKN Strategic Planning Committee. The prioritized areas for 2015 are: Realize sustained membership growth, establish financial security, expand signature activities, and grow alumni participation.

In order to meet the Strategic Goals and achieve the mission and purpose of IEEE-HKN as outlined in the society's proposed five-year plan, the Strategic Planning Committee proposes the formation of the following committees or task force groups to the IEEE-HKN Board of Governors as prioritized below:

Globalization Committee

This sub-committee will focus on the expansion of chapters in IEEE Regions 7-10, the support of existing chapters, and the development of a structure to support globalization.

Alumni Committee

This initiative is intended to re-establish alumni connections, alumni chapters, mentoring, distinguished lecturer series, alumni annual giving, an industry advisory committee, and to involve alumni and award recipients at all levels of IEEE-HKN.

21st Century Committee

The charge for this committee is to address and update the IEEE-HKN message and value proposition. This group will be responsible for membership, education/conferences, and communications/publications all to expand the services and programs of IEEE-HKN and establish new signature activities.

In addition, the Executive Committee of the IEEE-HKN Board of Governors will assume responsibility for establishing financial security and developing corporate partnerships.



The IEEE-HKN 2014 Board of Governors. From left to right, top row: Tim Kurzweg, David Jiles, Kenneth Laker, Mark Law, Stephen Goodnick; middle row: Kyle Lady, Mo El-Hawary, Catherine Slater, John Orr; bottom row: Nita Patel, Evelyn Hirt, S.K. Ramesh

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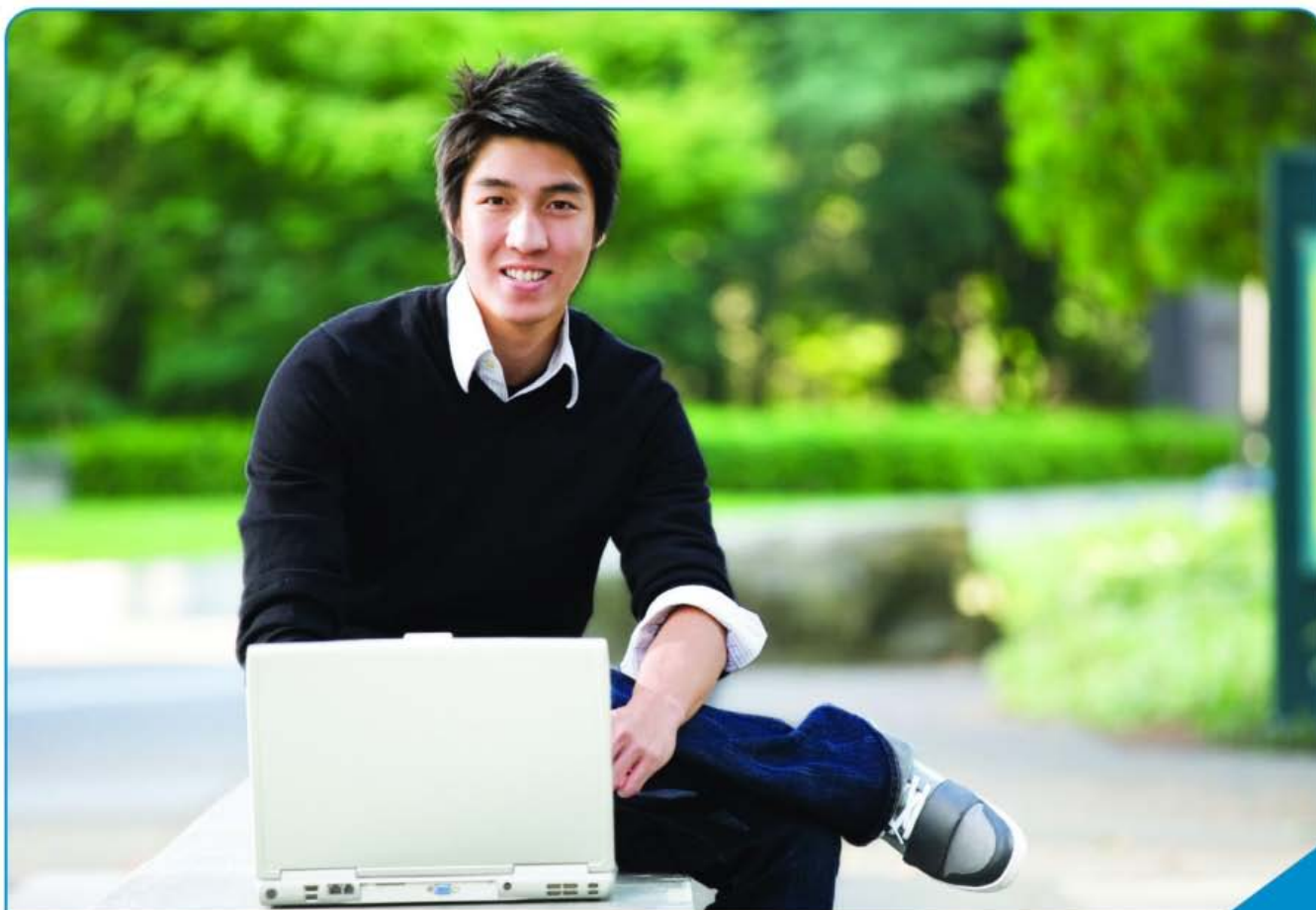
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Trial By Fire

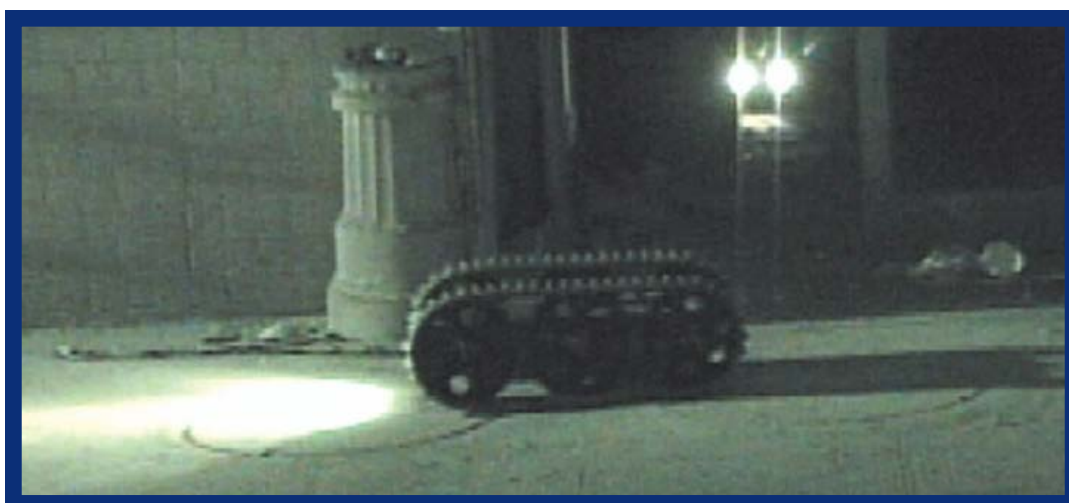
By Robin R. Murphy

Activities of the Rescue Robots at the World Trade Center from 11–21 September 2001

On 11 September 2001, the Center for Robot-Assisted Search and Rescue (CRASAR) responded within six hours to the World Trade Center (WTC) disaster; this is the first known use of robots for urban search and rescue (USAR). The University of South Florida (USF) was one of the four robot teams, and the only academic institution represented. The USF team participated onsite in the search efforts from 12–21 September 2001, collecting and archiving data on the use of all robots, in addition to actively fielding robots. This article provides an overview of the use of robots for USAR, concentrating on what robots were actually used and why. It describes the roles that the robots played in the response and the impact of the physical environment on the platforms. The article summarizes the quantitative and qualitative performance of the robots in terms of their components (mobility, sensors, control, communications, and

power) and within the larger human-robot system. The article offers lessons learned and concludes with a synopsis of the current state of rescue robotics and activities at CRASAR.

Robots were used for USAR activities in the aftermath of the WTC attack on 11 September 2001. The robots were on site from 11 September



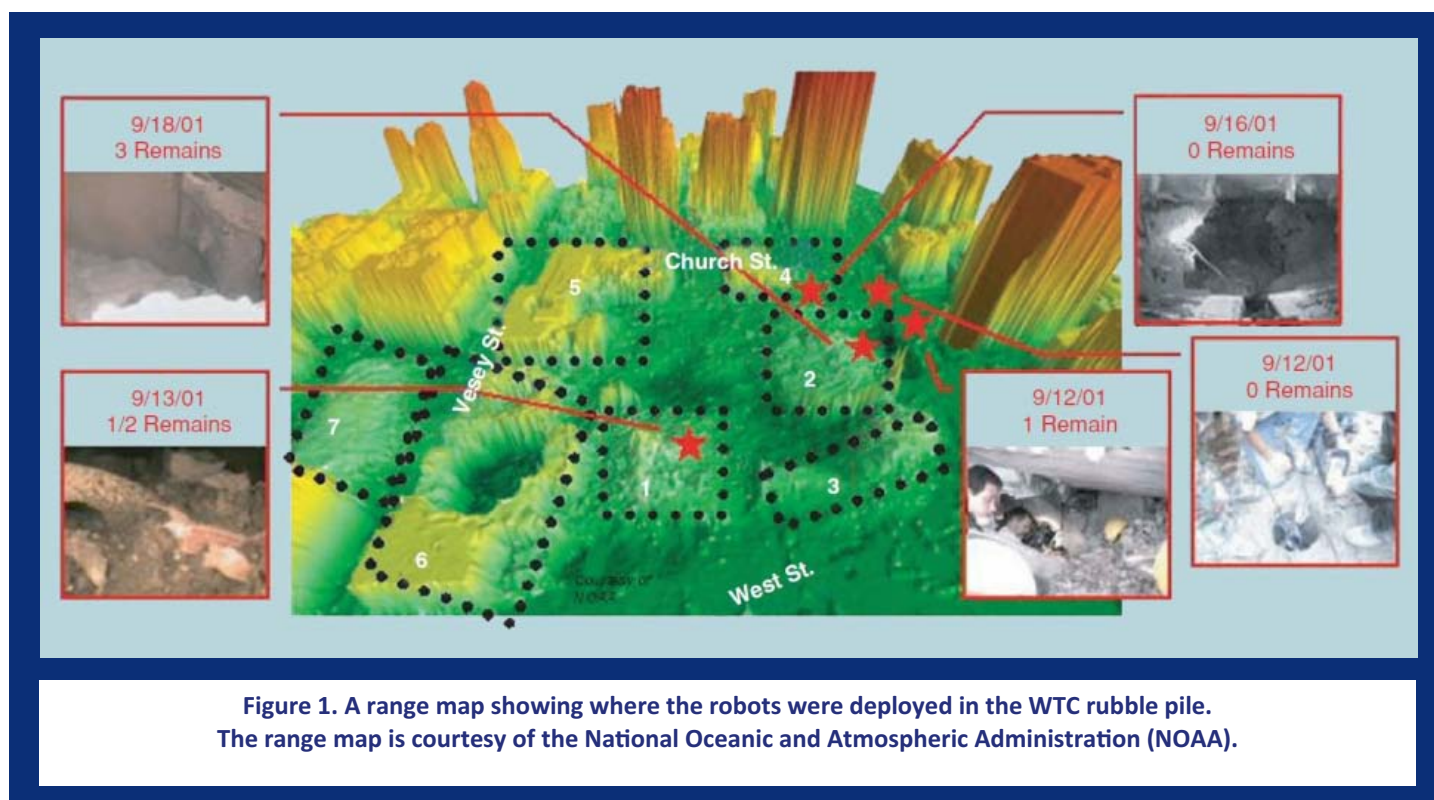
until 2 October 2001. This was the first known actual use of robots for USAR. The robots were used for:

- searching for victims,
- searching for paths through the rubble that would be quicker to excavate,
- structural inspection, and
- detection of hazardous materials.

In each case, small robots were used because they could go deeper than traditional search equipment (robots routinely went 5–20 m into the interior of the rubble pile versus 2 m for a camera mounted on a pole), could enter a void space too small for a human or search dog, or could enter a place still on fire or posing great risk of structural collapse. Though no survivors were discovered during the response, robots performed all their tasks well. The robots did find many sets of remains and, more importantly, were accepted by the rescue community. All robots were teleoperated owing to the unexpected complexity of the environment, the limitations of the sensors, and user acceptance issues.

Each robot deployment, or excursion into the disaster area for a workshift, was coordinated by the newly formed CRASAR under the direction of Lt.Col. John Blitch (retired). CRASAR worked as an independent team under the auspices of the Army Reserve National Guard, the New York Fire Department (FDNY), or the New York Police Department (NYPD), or served as an adjunct to Indiana Task Force 1, Pennsylvania Task Force 1, and Virginia Task Force 2, providing robots and operators plus training to task force members who might take the robots into areas offlimits to the CRASAR civilians. The Inuktun micro-Tracs and micro-variable-geometry tracked vehicle (VGTV) models and the Foster-Miller Solem and Talon models were the CRASAR robots used on the pile. The iRobot Packbot and Space and Naval Warfare Systems Command (SPAWAR) Urobot were used by CRASAR unofficially in nearby collaterally damaged buildings. Other robots and sensors from other organizations have been reported as being present, but were not fielded. For example, the U.S. Department of Justice brought in equipment from the Savannah River Technology Center, but only the sensors were used.

CRASAR coordinated four teams of scientists who worked during the rescue phase of the response (11–21 September), when there was still a possibility of survivors. Blitch and the first members of the teams from iRobot (led by Tom Frost) and Foster-Miller (led by Arnie Manigolds) arrived in the early evening of 11 September, while the USF team (led by Robin Murphy) arrived the morning of the next day. The U.S. Navy SPAWAR team from San Diego (led by Bart Everett) was unable to travel until the government permitted flights to resume, and so did not arrive until Friday, 14 September 2001. Figure 1 shows the locations where the robots were used on the rubble pile.



The scientists had varying degrees of relevant field expertise. Blitch had participated in the Oklahoma City bombing rescue efforts and subsequently completed a master's degree on robots for urban search and rescue under Murphy's coadvisement, continuing to publish and work in the area [1]–[3], [9]. In addition to numerous publications [5]–[8], [11]–[17], [19], [21] and research funding in rescue robotics, Murphy and two members of the USF team held actual certification in some forms of USAR. These were a side effect of conducting studies with Hillsborough County Fire Rescue since 1999. Members of the Foster-Miller and SPAWAR teams had military explosive-ordnance disposal experience.

The USF team also served as archivists—collecting, annotating, and backing up videotapes from the field, keeping up with the deployment details, and making field notes. Videotapes of the robot's-eye-view were made for each run, though the tapes from the two runs on 12 September were taped over. Videotaping of external surroundings was not permitted by the NYPD, so corresponding external views of the robots and where they entered the rubble pile are generally not available. The data collected from 11–21 September 2001 resulted in two master's theses, one concentrating on the performance of the robots in the field [10] and the other on human-robot issues [4].

A fifth team from U.S. Army Tank Automotive and Armaments Command - Army Research and Development Command - Explosive Ordnance Disposal technology division (led by David Platt) was brought in to assist Blitch and Foster-Miller with the recovery phase, 24 September to 2 October 2001. The teams frequently worked for the New York Department of Design and Construction in structural assessment of the slurry wall and foundations of the WTC complex. The experience of the fifth team is reported in an article [20], though that article does not accurately represent the activities and use of robots prior to 24 September, when that team was not involved.

The Robots at the WTC

The majority of robots used at the WTC response were either developed as part of the Tactical Mobile Robots program sponsored by the U.S. Department of Defense (DoD) Defense Advanced Research Projects Agency (DARPA) or were being used by contractors within the program. The Tactical Mobile Robots program had been managed by Lt. Col. Blitch up until a few months before 11 September 2001. Tactical mobile robots are small enough to be carried in one or two backpacks (also known as man-packable) and were intended for hostage rescue and military search and rescue with a clear dual use for civilian USAR.

Figure 2 shows the initial group of robots brought to the WTC. Only three models were actually used on the rubble pile from 11–21 September, for reasons described later. These models were the micro-Tracs, the Inuktun micro-VGTV, and the Solem, and are circled in the photograph. The robots either belonged to DARPA, the teams, or were sent by robot manufacturers.

Each of two Inuktun models could be carried in a backpack by one person. Both robots are tracked vehicles the size of a shoebox ($0.17 \times 0.32 \times 0.06$ m) and are teleoperated through a tether. The tether serves for both communications and power. An operator teleoperates the robot through a separate operator control unit (OCU), slightly larger and deeper than a laptop. Both robots have a color camera and two-way audio. The difference between the two vehicles is that the micro-VGTV is polymorphic, it can change its shape. Both models are designed for examination of heating, ventilation, and air-conditioning ducts and pipes. They do not have any inclinometers, odometers, or temperature probes, though newer models do. Neither are self-righting or invertible. The top speed for these robots is rated at 0.076 m/s, and the

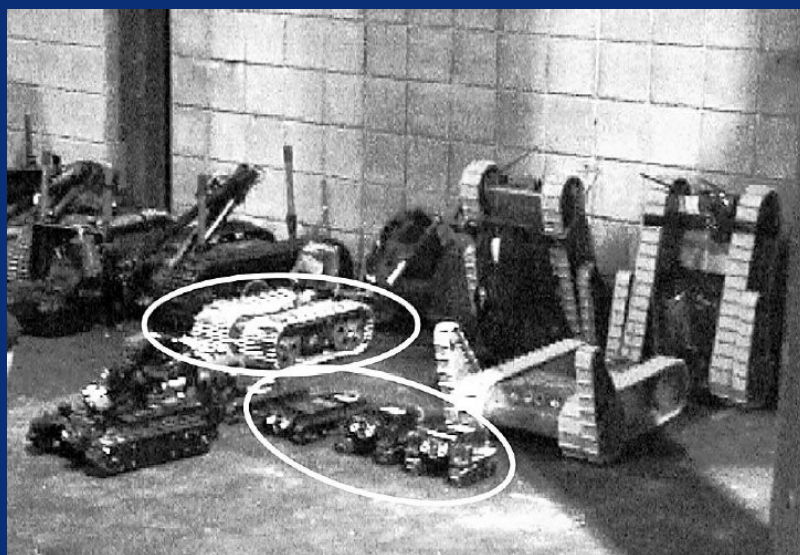


Figure 2. Robots on static display at the Javits Convention Center where rescue teams were housed from 11–21 September 2001. Robots that were used on the rubble pile are circled.

weight is 4.5 kg. The power supply is three 12-V batteries connected in series.

The Solem can be carried by two people. It is a tracked vehicle with wireless communication, a black and white camera on a tilt-up mast, and a laser range grid that can be projected onto the area in front of the camera for depth estimation (Figure 3). The robot weighs 15 kg and has a footprint of $0.51 \times 0.37 \times 0.2$ m. The operator teleoperates the robot through a separate OCU. The Solem does not have two-way audio. It is designed for military and civilian explosive ordinance disposal and has a top speed of 0.5 m/s. Four nickel hydride batteries serve as the onboard power supply. Although it is wireless, it was used with a safety rope, which imparted all the disadvantages of a tether.

The WTC Environment

The WTC environment was on the order of 80,000 m². The rubble pile formed the core of the hot zone, which is the area of devastation that poses significant safety risks to rescuers. Although the rubble pile was surrounded by buildings that were also collaterally damaged, these buildings were given low priority for search and rescue activities, in part because it was likely that occupants had exited from the building, and because the rescue focused on finding trapped first responders. As described in the following, the hot zone terrain was much different than an earthquake, especially in terms of the materials comprising the collapse and the types of voids. This made robots necessary and also presented favorable conditions for their deployment.

The WTC disaster was significantly different than an earthquake scenario, or even other terrorist attacks on buildings (Oklahoma City, Khobar Towers, etc.). The WTC was primarily constructed of steel, with concrete used only for flooring, while most commercial buildings and bridges are primarily constructed of concrete with steel reinforcement. The design of the WTC towers was unique. As a result, the collapse was a pancake type, where the buildings largely came straight down with few voids above the street level (Figure 4). The rubble was all steel, which is difficult to cut and remove, and the response teams were not trained to handle steel. The voids open to the surface were generally less than 1 m wide and still radiating heat from the jet-fuel fire in the basement. This meant that traditional methods, such as canine search, were not effective. None of the robots are designed to operate in temperatures higher than a person can tolerate.

The collapse type resulted in a situation where any chance of survivable voids was expected to be below grade in the basement areas. As a result, the bulk of the rubble above grade was not of interest and needed to be removed as quickly as possible in order to gain access to the basement. However, without being able to



Figure 3. A view from a Solem as it projected a range grid into a void in the area of WTC Building 4.



Figure 4. View of the rubble near WTC Tower 2 and Building 4 showing pancaking and the lack of voids.

see the interior of the rubble, an efficient rubble-removal strategy that would speed up access to the basement could not be created. Therefore, the robots were needed to enter the extremely small voids and see if there was a way further down.

The voids themselves were generally more favorable to robotic exploration than a regular rubble pile, though far more demanding than the NIST Standard USAR Test Course developed for RoboCup [16]. Debris that typically causes problems, such as furniture, carpeting, and window coverings, were burned away or pulverized. Concrete chunks that pose hard-to-climb obstacles for most robots were not present because there was no structural concrete in the buildings. However, most voids were filled with paper, and the robots often sank deep into the paper and couldn't see or climb on top. The robot's camera was occluded an average of 18% during each run [10].

The majority of voids were the insides of the steel structural members, which had a hollow rectangular cross section (0.3×0.6 m) and were over 10 m long. These "box beams" acted like straws, penetrating the rubble. Figure 5(a) shows a contextual view of the WTC Tower 2 rubble pile with the box beams visible on the pile, Figure 5(b) a box beam that was explored by the robots, and Figure 5(c) a view from the robot as it investigated that void.

The Packbot and SPAWAR Urbot were used unofficially in collaterally damaged buildings for a few hours. The buildings were largely intact, which suggested that it would be favorable to larger robots. However, the insides were dark and covered with thick dust and mud from the sprinkler system, which made it difficult to get traction and for the human operator to recognize key attributes of the environment. The robots ran into expected challenges (closed doors) and unexpected situations (the mud on the stairs reduced the traction and the Packbot could not climb all the way up).

The WTC was also unusual in that it did not present major decontamination challenges for the robots. Unlike an earthquake or other mass casualty events, the remains of victims were severely burned. There was no blood or body fluids that would have to have been carefully washed off between runs and would have necessitated the use of medical protective gear for the robot operators.

Another aspect of the environment that affected robots and their deployment was the location of the cold and warm zones. A cold zone is where the rescue workers rest and rehabilitate their equipment, whereas a warm zone is the area immediately surrounding the hot zone. Rescue workers stage and decontaminate equipment in the warm zones, as well as remain on stand-by. The hot and warm zones were divided into sectors owing to the large size of the rubble pile. The warm zones at the WTC were subdivided into a base of operations (BoO) and a forward station.

The cold zone for federal response teams was at the Javits Convention Center, four miles away. Transportation between the Javits Center and the BoO was through commercial buses. If a robot did not fit in the luggage bays of the bus or on the seat inside the bus, it was not permitted to go to the warm and hot zones. Exceptions were not made until after 21 September. Figure 6 shows the CRASAR camp at the Javits Convention Center.

The warm zones were a three-block area surrounding the hot zone. Teams usually set up the BoO within an evacuated building. At the BoO, they stored equipment, watched CNN, rehydrated and ate, and took naps. Impromptu, or hasty,

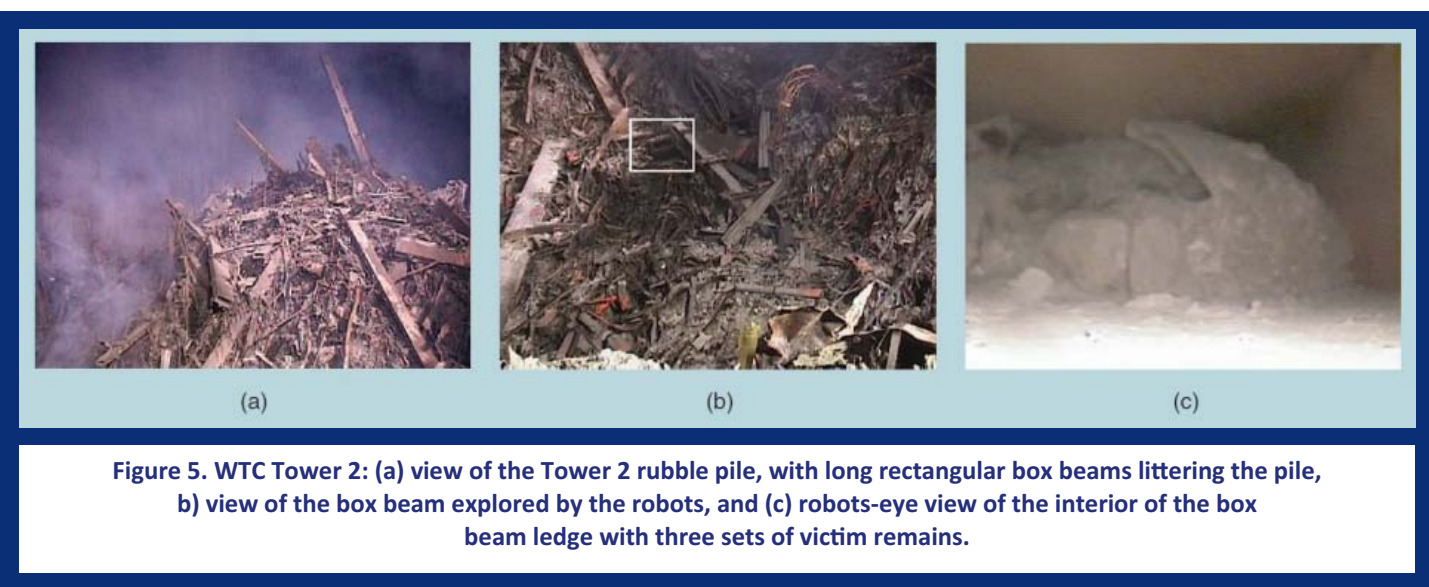


Figure 5. WTC Tower 2: (a) view of the Tower 2 rubble pile, with long rectangular box beams littering the pile, (b) view of the box beam explored by the robots, and (c) robots-eye view of the interior of the box beam ledge with three sets of victim remains.

training on the robots was also held in the BoO. Hasty training for the federal teams was needed because, in the case of a particularly dangerous void, technical search specialists from the federal response team would have transported and operated the robots rather than expose the CRASAR civilians to a significant safety risk.

When a new area became available for technical search, operators would prepare the robots, pack them in their backpacks, and walk the three blocks to the forward station. At the forward station, the robots would remain powered up on "hot stand-by" until the area was deemed safe for human entry. Then, the robots would be called into the pile and escorted to the site. The robot operator would have to crawl over rubble and walk across beams or down straight ladders to get to the area of interest. Often, the robot and operator would have to evacuate from the rubble pile before reaching the void due to safety concerns.

Robot Roles and Missions

The robots were deployed eight times over the 11–21 September time period, but only used on four of those shifts. The purpose of each deployment was best described as technical search: trying to find deeper survivable voids within the rubble pile or less dense areas that could be more rapidly excavated, providing access to the basement where there might be survivors. In a more typical response, the technical search would have been more focused on finding survivors.

As noted earlier, the type of collapse and the density of the debris resulted in many extremely small voids. These voids could not be effectively examined by dog teams because the fire interfered with the scent and, later, rain washed off any residue. The voids were often very deep, precluding the use of search cameras on poles, which could only see about 2 m into the void. Many search cameras melted in the early hours of the WTC response when they were thrust into voids still on fire.

In future responses on a rubble pile, it is expected that a canine team or acoustic sensors would identify an area where there was some sign of a human. Voids within that area would first be examined by a search camera, then deeper voids would be investigated by the robots.

From the arrival of the first robots on the evening of 11 September through the morning of 13 September, the robots were deployed under the direction of the Army Reserve National Guard, the FDNY, or the NYPD. A CRASAR team would talk directly with a sector chief or other authority on the rubble pile and then be directed to a void. After 13 September, access to the rubble pile was formally controlled, and the robots were most often deployed as part of a federal task force team operating under the Federal Emergency Management Agency (FEMA), where CRASAR essentially acted as a server and processed requests for robots from client task force teams. In most cases, CRASAR operators accompanied FEMA Indiana Task Force 1. The micro-Trac was the most frequently used robot, deployed seven out of eight times. The micro-VGTV was second, and the Solem was used only once.



Figure 6. The CRASAR camp within the Javits Convention Center where team members rested, repaired or modified robots, or archived field data. Gary Mouru (Foster-Miller) is in the foreground, Brian Minten (USF) is in the middle, and Mark Micire (USF) is in the rear.

Choice of Robot for a Run

The choice of a robot for a run depended on four factors:

- transportation restrictions,
- the robot's acceptance by the requesting authority,
- the expected size of the void to be investigated, and
- any other contextual information.

Each factor is described below.

The transportation restrictions introduced earlier meant that only man-packable robots were permitted on the rubble pile during the rescue phase. This reduced the fieldable pool to the Inuktuns, the Solem, and the Packbot. These restrictions were relaxed in the recovery phase, and the pool became the Inuktuns and the Solem and Talon. (The Packbot was no longer available.)

An authority such as the leader of a FEMA task force would discuss their needs with CRASAR and determine which robots and operators they would take with them. The task force was responsible for the safety of the CRASAR members and also had the discretion of accepting training on the robots so that they could be deployed by one of their technical search specialists. Therefore, they tended to choose robots that were easier to operate. The Packbot was rejected by FEMA teams, despite its mobility advantages for larger voids, because it was still obviously in its early prototyping phase.

The void size was another important factor in what robots were requested. The choice of which Inuktun (micro-Trac or micro-VGTV) to use, or whether to use an Inuktun or Solem, was largely a function of the size of the void. Most of the voids were less than 1 m diameter, so the smaller Inuktun robots were always chosen. At the end of each shift, the task force teams would debrief the next shift about the area they would be working in. The teams would then request the robot(s) they thought most appropriate.

In addition to picking a robot, the task forces were concerned about the field expertise of the operators. Robot operators who could operate the Inuktuns and had direct USAR experience were preferred. Robot operators with no field experience did not go onto the pile, since that was the most dangerous location. An operator with field experience required less supervision than a civilian with no training and diverted less of a task force's manpower away from the search and rescue task.

Context-dependent information, such as time constraints, were also important. In one deployment, the larger Solem robot was used because the window of opportunity to explore that newly opened void was only 20 min (at which point the cranes were to resume working in the area and all personnel would have to be evacuated for safety reasons). In that case, a crane operator had opened up a large network of three tunnels, one of which appeared to be related to the subway and food court areas. A rescuer could crawl on hands and knees in the tunnels, though the time to get permits for a safe entry was longer than 20 min. The Solem is more than three times faster than an Inuktun and was more likely to climb the more irregular rubble, therefore it was selected.

Pattern of Use

The pattern of use for the robots was surprising, and quite different than what the USF team had experienced in previous training [6]. The robots were called out eight times, though used only on four deployments, and inspected a total of eight voids (Table 1). This may appear low. Indeed, it is likely that the robots were

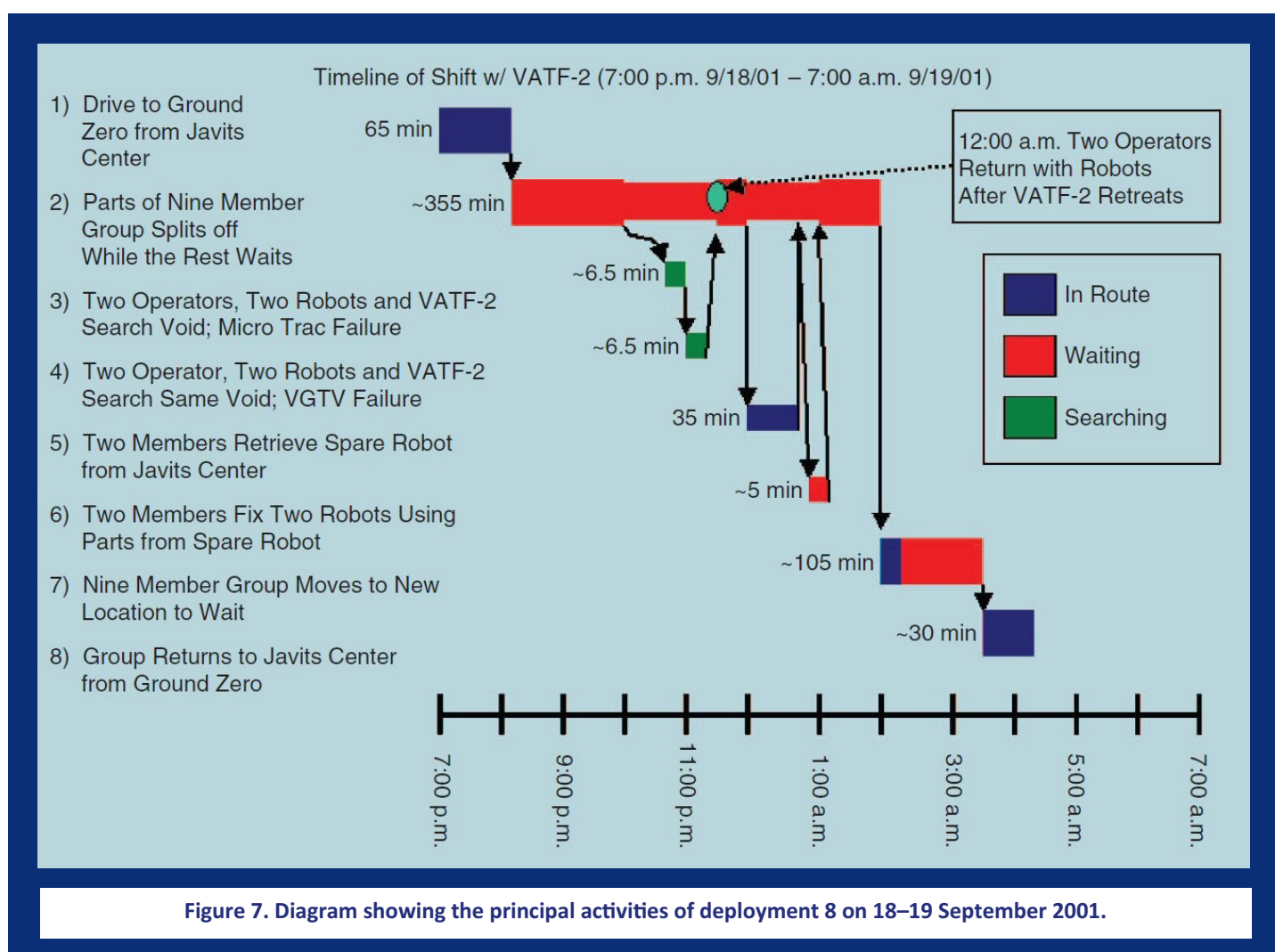
Table 1. Date of deployments and voids searched, showing the location and the robot used.

Deployment	Void	Location	Date	Robot Used
1	1, 2	Cedar St.	9/12/01	micro-Tracs
2	3, 4, 5, 6	WTC 1	9/12–13/01	micro-Tracs
7	7	WTC 4	9/16–17/01	Solem
8	8	WTC 2	9/18–19/01	micro-Tracs, micro-VGTV

underutilized. This is due in part to the fact that the robots were a new technology that none of the task forces knew about. (Many task forces assumed the robots were the much larger, and inappropriate, explosive ordinance disposal robots used by bomb squads. CRASAR now conducts awareness training and plenary talks at emergency management conferences to educate the USAR community.) The primary reason for the low use is that there were few search opportunities at the WTC; the search and rescue teams themselves often spent an entire 12-hr shift without being able to get on the pile or to initiate a technical search due to safety considerations.

It is also surprising that the average time that a robot was in a void was a mere 6:44 min, with the longest time logged at 24:40 min. This is consistent with the nature of search and rescue, where voids are quickly searched but the follow-up extrication may take hours. In previous exercises [6], the robots were used to search rooms and buildings still standing— providing a much larger area. In the case of the WTC, the robots were used to explore confined space or smaller voids. The CRASAR team has participated in three training USAR exercises since the WTC with realistically damaged buildings. The robots tend to be deployed for either highly confined space voids (which may be shallow) or for quick excursions into partially structured areas. Therefore, it is expected that a 30 min or less run will be the norm for victim search. It should be noted that, because a technical search is so short and a search camera transmits images with a flip of a switch, rescuers would not accept a long boot or setup time for a robot. Rescuers walked away from the robots on several occasions. The CRASAR teams realized that the robots had to be kept on “hot stand-by” so that the time from the technical search specialist saying “look here” and the robot in the void transmitting an image was cut to under 2 min.

Figure 7 shows a representative shift, which is discussed in more detail in [4]. In this shift, robots were requested by Virginia Task Force 2 to investigate the void on WTC Tower 2 [Figure 5(b)] during the evening shift. The team spent only 13 min out of the 12-hr shift searching the voids. The majority of time was spent waiting.



After 24 September, the robots were more commonly used for structural inspection and hazardous material detection, particularly to see if explosive gases were present. One of the robots was outfitted with a Multi-RAE, a gas detector commonly used by fire departments throughout the United States. The duration of the robot runs after 24 September (the recovery phase) were longer than the search for victims during the rescue phase. This was in part due to the nature of detailed structural inspection, as well as the reduced urgency.

Performance of Robots by Components

The robots performed well overall, with the primary measure being the acceptance by the rescue community. The robots did find multiple sets of human remains, but technical search is measured by the number of survivors found, so this statistic carries little weight within the rescue community. The performance of the robots may be better understood if described in terms of the components of the robots: mobility of the platform, sensors and sensing, control, and wireless communications. The fifth component, power, did not show any problems. All the robots were powered by batteries, which were sufficient to run the robots for a 12-hr shift.

Platforms and Mobility

The robot platforms generally performed well. The most common problems were with the tracks on the Inuktuns. A micro-Trac was damaged when a 0.25-in piece of metal, possibly from office furniture, became jammed in the 0.125-in gap between the tracks and the body (Figure 8). In one case, an Inuktun detracked one of its treads, had to be pulled out of the void, and the mission had to be suspended until a replacement track was brought to the site. The detracking is thought to have been due to the high heat in the void softening and permitting the rubber track to expand and come off.

The biggest fear, though unrealized, was a robot flipping over into a position where it could not be righted. None of the robots used on the rubble pile were invertible or selfrighting. This put considerable pressure on the robot operators. The only time a robot (the Solem) flipped over, it was able to be righted by a judicious set of pulls on the safety rope. The micro-VGTV had an advantage in climbing rubble since, with its variable geometry, it could be configured to have a slightly raised bow, like a tank. However, the slightly heavier micro-Tracs was often better for smoother surfaces.

One unexpected outcome of the WTC was the high dependency of robots on tethers or safety ropes. This introduces the need for a second operator, where one

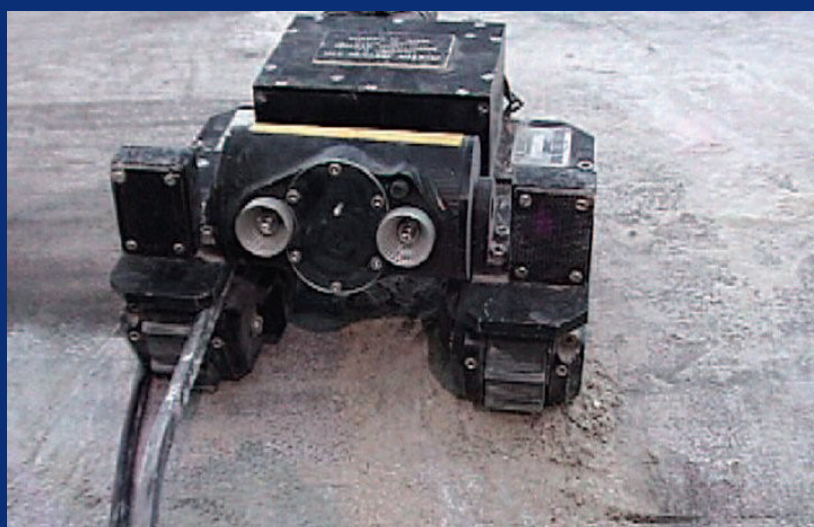


Figure 8. Metal rod jammed between the tracks and housing on an micro-Tracs robot.



Figure 9. Arnie Mangolds handling the tether for a robot inserted into a lean-to void across the street from WTC Tower 2.

operates the robot (the operator) and one handles the tether (the tether wrangler) (Figure 9). The size of most voids permitted only the Inuktun robots to be used. The small size of these robots is possible only by having the battery located with the OCU and all power and control transmitted through a tether. In the one run where a wireless robot was used, a safety rope was needed since there was always the possibility of a vertical decent or flipping the robot over.

Tethers and safety ropes had a significant disadvantage: they tangle. During the rescue phase, a robot tether got tangled and could not be retrieved without an intercession. In this case, the robot had gone from street level down into a boiler room. On the way back up, the tether became entangled with steel reinforcement bars (rebars). Since the robot had uncovered a promising void, rescue workers immediately shored up the void and entered. They retrieved the robot on their way into the void. The study of the videotapes by Micire [10] indicated that an operator had to pull on the tether an average of 7.75 times per drop, or approximately once a minute, in order to keep the tether from getting tangled.

However, tethers and safety ropes had additional advantages beyond keeping the robot small. In the case of the Solem, the safety rope made it possible to self-right the robot when it flipped upside down. Unfortunately, the Solem was lost when the safety rope broke during an attempt made to retrieve it. (The robot operators swapped to steel cables during the recovery phase.) In the case of the Inuktuns, the operator handling the tether could work with the robot operator and actually help the robot climb obstacles or work the robot deeper into the rubble. These gravity assists occurred an average of 9.25 times per drop [10]. Note that the gravity-assists, combined with proactive pulling to prevent tangling, meant that that tether operator interacted with the tether more than two times per minute.

Sensors and Sensing

The most commonly used sensors were the video cameras. The Inuktuns had color cameras while the Solem had a black and white camera. Each robot had some form of headlight, with adjustable headlight intensity on the Inuktuns. The color camera is preferable for searching for victims. Since the interior of a building collapse is covered in gray dust from concrete and sheet-rock, the presence of a colored region may indicate a survivor who has shaken off some dust or is bleeding. However, black and white cameras are considered better for structural assessment owing to their slightly higher resolution.

CRASAR also had a number of Indigo Alpha forward looking infrared (FLIR) miniature cameras for thermal imaging from USF and on loan from the U.S. Army Night Vision Laboratory. These cameras are the size of a small cell phone and could be mounted on most robots. Thermal imaging is a popular sensor with fire rescue teams for at least two reasons. First, victims will produce a heat bloom, despite being nearly invisible to the naked eye, due to the coating of gray dust. Second, the thermal imagers can detect signs of excessive heat build-up, indicating a flash fire is incipient and that rescuers should evacuate. Unfortunately, the FLIR quickly proved not to be useful. The rubble pile interior was extremely hot, so any signs of survivors or structural cracks would have been masked.

One of the biggest difficulties encountered while using the video cameras was the lack of depth perception. The Solem had a range grid that could be projected onto the scene in front of the cameras, but that was hard to interpret. Another problem with the video was the lack of peripheral vision or feedback. The robots would often roll over something or get trapped against an obstacle just off to the side.

The use of a Sick laser ranger was not possible for the Solem or the Inuktun. The Solem does not have any on-board computer or mechanism for relaying that data, and the Inuktuns cannot support a payload that size. Besides, the efficacy of a single planar laser is unclear—the robots must go through spaces that are heavily confined in all three dimensions. Estimating head clearances was a major problem at the WTC and unlikely to be resolved with a single laser and poor odometry.

Odometry was available on the Solem but not of use. The extreme terrain quickly invalidated the readings. The Inuktuns did not have odometry, and distance traveled was estimated by the length of the tether in the void. GPS signals would have been impossible to reliably acquire within the rubble due to the density and composition of the construction material. The Urbot operators employed a fairly useful strategy while operating in the collaterally damaged buildings—the odometry was reset periodically, and all distances were relative.

Control

All the robots at the WTC response were teleoperated. Neither the Inuktuns nor the Solem are equipped with an interface to permit computer control. Some forms of semiautonomous control or artificial intelligence for USAR had been demonstrated, but could not be used for a variety of reasons. USF, at one time, had a homemade computer interface for the Inuktuns, but it had broken and had not been replaced. The Packbot had an onboard computer and a computer as the OCU, but no software for autonomous control was available even if had been chosen for deployment. This was unfortunate since the iRobot Urban, the alpha version of the Packbot, had software developed for the Tactical Mobile Robot program. The software permitted the Urban to detect when it was flipped over and to right itself. Mapping software had also been written for the Urban but required the use of Sick lasers and accurate odometry. Perceptual cueing software agents, which detected skin color, heat, changes in color, and motion, had been developed for victim (or intruder) detection. The cueing software had been demonstrated on an Urban at the Montgomery County Fire Training Academy a year earlier. Unfortunately, the Packbot was not backwardly compatible with the Urban, and the software could not be readily transferred.

Wireless Communications

Only one wireless robot (the Solem) was used one time during the 11–21 September 2001 time period, and it was lost in the field due to wireless dropout. The Solem used a radio frequency that is normally good for 4.8-m line-of-sight transmissions. However, within the rubble, the Solem experienced 1:40 min of intermittent wireless dropout, and, at 7:00 min into the run, the connection was lost altogether as it returned to the entry point. The robot was estimated to be within 30–40 ft of the entry. An attempt

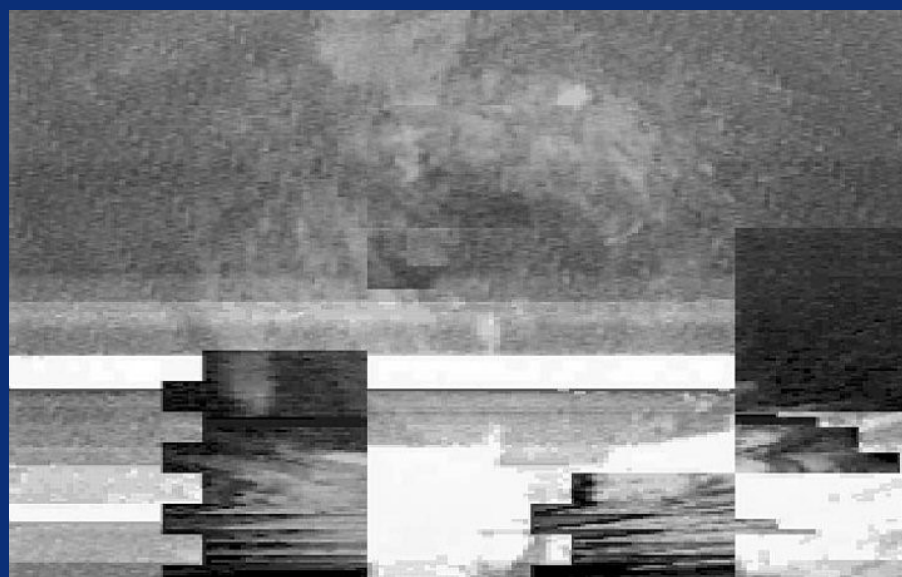


Figure 10. Frame from video of Solem as it experienced 1:40 minutes of communications loss during a 7:00 min exploration of a void in WTC Building 4.

was made to recover the robot by pulling its safety rope, but the rope broke. The robot was never recovered. Figure 10 has a representative image transmitted by the Solem that was not considered dropout. An important note about wireless communications is that the Solem, as well as the Packbot and Urobot, transmit video data using unencrypted, lossy compression algorithms. Lossy compression reduces bandwidth, but it strips out information critical to computer vision enhancements and artificial intelligence augmentation. A second concern about wireless communications is that unencrypted video might be intercepted by a news agency, violating a survivor's privacy.

Performance of Robots Within the System

Since the robots were teleoperated (and are likely to be so for the near future), it is instructive to view their performance within the larger human-robot system. The primary source of errors stem from poor user interfaces or from fundamental limitations of human perception.

In terms of quantifiable errors, the videotape analysis [10] reported that the robot operators made both mistakes (an intentional error or doing the wrong thing) and slips (an executional error in how to do the right thing) [18]. Approximately 10% of the duration of runs with the Inuktuns showed the same mistake. Experienced operators spent significant time adjusting the headlights, despite being aware that the video camera had auto gain optimization, essentially cancelling out any adjustment. The operators reported that they were trying to do something, anything, to get a better view of the highly deconstructed and unfamiliar environment.

The tapes revealed three types of slips: collisions, platform high-centered, and platform in the wrong configuration. There were an average of 0.25 collisions per drop, probably due to oversteering by the operator. For an average of 8.9% of the duration of a run, the robot was either high centered on a piece of rubble or in the wrong configuration. These slips appear to be the result of a lack of sensors and poor user interfaces.

A less quantifiable but very important error was missed remains. This is not quantifiable, since there is no ground truth. Figure 5(c) shows a view of three sets of remains: a torso to the left of the alley, a head near the center (with a wristwatch on the far right), and a hand in the alley. Only the torso on the left was identified at the WTC, despite repeated viewing by numerous task force members. The other remains were only noticed on a review of the videotapes back in Tampa by Hillsborough County Fire Rescue, and later verified by others. This shows that unaided human perception, especially impaired by physical and cognitive fatigue, may not be sufficient for search and rescue.

Lessons Learned and Observations

The WTC response provided many lessons for the robotics community. These lessons can be distilled into:

- the overall scenario for use of mobile robots,
- recommendations for a rescue robot system, and
- observations as to the practicality of fully autonomous rescue robots.

Platforms must be man-packable in order to be used, but there is no one right size. A color video camera and two-way audio should be on each platform, with the OCU capable of recording video data. Both the robot and the OCU should be water-resistant and readily decontaminated.

Scenarios

Based on the WTC, six field studies conducted by CRASAR with rescue workers since 11 September, and our experiences with the CRASAR international robotics response team, now recognized by the United Nations, the role of robots in search and rescue is becoming more clear. Small robots are proving especially effective for two situations: very small, deep voids, smaller than a human could crawl into or deeper than a boroscope can penetrate, or larger semistructured voids that humans cannot enter until it has been declared safe (a process that takes up to 8 hr). The variance in void sizes and the numerous activities now enabled by rescue robots (search, structural and hazards assessment, and medical facilitation) precludes a single ideal platform and payload. Instead, operators and robots mirror the interaction and deployment of human-canine teams.

It should be noted that the field experience indicates that robots will be used much like dogs. The robot operator will carry the robot to a void identified by rescue workers performing reconnaissance, insert the robot into the void, work with other rescue professionals to assess the data being provided by the robot, and then remove the robot and move to the next void. Scenarios where a swarm of hundreds of robot insects are set loose to autonomously search the rubble pile and report to a single operator appear to be both physically impractical and at odds with the larger rescue organization.

Recommendations for a Rescue Robot System

In terms of platforms and sensors, there is no single right size for a rescue robot. Both the Inuktun and the much larger Solem were used on the rubble pile, and the fully developed Packbot would have been used. The size of the void influences the size of the robot. Based on transportation issues, a rescue robot should be man-packable. Also, a rescue robot will always have to have at least a safety rope, so the design of the platform should specifically incorporate that feature. It is desirable for wireless robots to have a communications tether that can be attached to the safety line to eliminate communications drop-out.

The mobility characteristics for a platform cannot be specified, since the different types of terrain corresponding to different void types is as yet unknown. There is no known characterization of rubble terrain that would indicate the necessary clearances needed for robots or even project energy consumption. Any platform design should take into consideration that the robot is likely to flip over at some point. It appears that invertibility is more desirable than self-righting, since the robot may not have enough room to execute a complex set of self-right motions.

Regardless of the size, each robot system should have the following components for technical search. It should have at

least a color video camera and two-way audio (to enable rescuers to talk with a survivor). The OCU should be able to record and play back video data. If a victim or structural condition is found, it will be helpful for the members of the task force command structure and extrication crew to be able to view the tapes. It is desirable for the OCU to support computer vision algorithms to enhance the image (e.g., color histogramming) or to perform perceptual cueing. The robot should allow for at least one additional camera (FLIR or black and white) to be added as needed to meet specific mission needs. The desirability of having platforms that support the addition of payloads for hazardous material assessment, structural assessment, and victim management cannot be overemphasized.

The robot and OCU should be waterproof or, at the very least, water resistant. Building collapses often are muddy, with pools of standing water, because of water from broken sewer pipes and the release of the sprinkler system. A rescue robot also needs to be water resistant so that it can be decontaminated. Most biological decontamination agents are a weak (2–5%) solution of chlorine bleach, though rescuers are shifting to more equipment-friendly alcohol-based solutions. Finally, the robot and OCU need to be waterproof to be able to operate in the rain and snow.

Autonomous Control

Autonomous control appears unrealistic at this time and undesirable for the near term. It is unrealistic because of the challenges previously described. It is undesirable because rescue workers do not trust full autonomy, and user acceptance is critical for the field of rescue robotics. The term “autonomous control” may also create confusion. Autonomous navigation may be more likely to be achieved with the advent of miniaturized range sensors, but autonomous detection of victims may be extremely difficult, owing to the inherent challenges of computer vision under unstructured lighting conditions.

The USAR terrain is very difficult for humans to teleoperate through. The viewpoint from the robot is very low to the ground with a narrow field of view, and the rubble is disorganized by definition. Automating navigation is expected to be very difficult. It is quite different than going down a hallway with a smooth floor or even going outside on a sidewalk or a park. In USAR, the density of obstacles is much higher, and the robot cannot often go around. Behaviors for climbing obstacles with polymorphic vehicles will become increasingly important.

Another challenge for fully autonomous navigation is how to operate in the truly three-dimensional nature of the space. There are hazards both above and below the robot, and the robot will most likely have to descend vertically at some point. The spaces for navigation are much more confined than in any other previously proposed domain for mobile robots, and the lighting is uncontrolled. It is expected that miniature range sensors will be needed to provide the data necessary for truly autonomous navigation.

As seen in Figure 5, victims may be unrecognizable to the human eye. Computer vision is nowhere near the level of human perception, so it is unlikely that unassisted machine perception will be able to produce no false negatives (miss a victim) while minimizing annoying false positives. Computer image enhancements and cueing of interesting regions for human detection appears promising.

Conclusions and Future Work

The first use of robots for USAR was successful, and the robots were well received by rescue professionals. The robots were called out onto the rubble pile for rescue operations eight times in the 11–21 September 2001 time period and actually used on four of those deployments for an examination of eight voids on WTC Tower 1, Tower 2, Building 4, and adjacent areas. The robots were tasked with victim and structural search, focusing on identifying shortcuts to the basement or possible survivable voids. Only one robot was lost in the field during that time, and that was due to a wireless communications failure. While the research issues for rescue robotics span computer science, all the engineering disciplines, as well the life sciences, the need for mechanically superior platforms cannot be underestimated.

Rescue robotics for USAR is still in its infancy. There are no robots made explicitly for USAR. The models of robots used at the WTC have a long delivery time owing in part to the competing demand by the U.S. military for operations in urban terrains. CRASAR is now based at the USF under the direction of Prof. Murphy and has cooperative agreements with the International Rescue System Institute in Japan. In addition to pursuing research, CRASAR maintains the only known trained and equipped rescue robotics response team in the world. As of this writing, no FEMA teams have

rescue robots, though CRASAR is working with several to set up memorandums of understanding to deploy with them.

One possible road map for rescue robotics research was presented [19]. In order to maximize the short-term benefit, it was recommended that research should concentrate on helping the teleoperator perceive the environment and search for victims. Remains were missed at the WTC, and to miss survivors in another response would be tragic. Research into user interfaces and semiautonomous and cooperative control should enable an operator to more easily teleoperate the robot while under extreme physical and cognitive fatigue and to not miss victims or key structural defects. In the next five to eight years, advances in platforms and sensors should enable a more complete situational understanding of the environment. Serpentine robots and miniature sensors that can penetrate more deeply into the rubble are a must. Simultaneous localization and mapping of highly confined spaces will create accurate maps to help the incident command better manage the extrication of survivors. Many techniques have been created that would be useful if only the sensors were small enough to use with man-packable mobile robots. In the next eight to ten years, advances in the civil and biomedical engineering disciplines, combined with telemedicine, should lead to robots that can care for unconscious, trapped victims.

Since the WTC, CRASAR has focused its research efforts on human-robot interaction to create better, cooperative interfaces, medical missions, and shoring and extrication. CRASAR has collected ethnographic data at three collapsed buildings, performed training exercises since 11 September, and continued to develop deployment and training strategies, as well as identifying the requirements for platforms and sensors. CRASAR has contributed to the development of a lightweight medical triage sensor, which is being commercialized, and a fluid delivery system for victim management. A new project is concentrating on the use of robots to emplace airbags and structural supports within the rubble pile to speed up extrication of survivors.

The tapes from the WTC and subsequent training exercises are available for scientific use on mini-DV or VHS from CRASAR. Edited photos and videos can be downloaded from <http://www.crasar.org>. (Due to the presence of human remains on the videotapes, unedited data sets are not released to the public.)

Acknowledgments

The effort described in this article used equipment purchased under funding from DARPA, the National Science Foundation (NSF), Office of Naval Research (ONR), and Science Applications International Corporation (SAIC). The author would like to especially thank Jenn Casper, Mark Micire, and Brian Minten for their efforts at the WTC and help in the data collection and analysis, all robot and rescue teams who worked with CRASAR, and Jen Carlson for her help in the preparation of this manuscript.

References

- [1] J. Blitch and R. Murphy, "Alternative scenarios for military deployment of unmanned ground vehicles," in Proc. 2nd Conf. Robotics Challenging Environments, 1996, pp. 36–42.
- [2] J.G. Blitch, "Artificial intelligence technologies for robot assisted urban search and rescue," Expert Syst. Applicat., vol. 11, no. 2, pp. 109–124, 1996.
- [3] J.G. Blitch and R. Mauer, "Knobsar: A knowledge based system prototype for robot assisted urban search and rescue," Simulation, vol. 66, no. 6, pp. 375–391, 2000.
- [4] J. Casper, "Human-robot interactions during the robot-assisted urban search and rescue response at the World Trade Center," M.S. thesis, Dept. Comput. Sci. Eng., Univ. South Fla., 2002.
- [5] J. Casper and R. Murphy, "Robocup/AAAI 2001 urban search and rescue competition data collection results," submitted to IROS 2002.
- [6] J. Casper and R. Murphy, "Workflow study on human-robot interaction in USAR," in Proc. ICRA 2002, pp. 1997–2003.
- [7] J. Casper and R.R. Murphy, "Issues in intelligent robots for search and rescue," in SPIE Ground Vehicle Technology II, Orlando, FL, 2000.
- [8] J. Casper and R.R. Murphy, "Human-robot interaction during the robot-assisted urban search and rescue effort at

the world trade center," IEEE Trans. Syst., Man Cybern. B, vol. 33, no. 3, pp. 367–385, 2003.

[9] J. Blitch, R.R. Murphy, and T. Durkin, *Mobile Semiautonomous Robots for Urban Search and Rescue*. New York: Marcel Dekker, Inc., 2002, pp. 211–224.

[10] M. Micire. "Analysis of Robotic Platforms Used at the World Trade Center Disaster," M.S. thesis, Dept. Comput. Sci. Eng., Univ. South Fla., 2002.

[11] R. Murphy, M. Ausmus, M. Bugajska, T. Ellis, T. Johnson, N. Kelley, J. Kiefer, and L. Pollock, "Marsupial-like mobile robot societies," in *Proc. Agents 99*, 1999, pp. 364–365.

[12] R. Murphy, J. Casper, J. Hyams, M. Micire, and B. Minten, "Mobility and sensing demands in usar," In *IECON-2K: Session on Rescue Engineering*, 2000.

[13] R. Murphy and J. Sprouse, "Strategies for searching an area with semiautonomous mobile robots," in *Proc. 2nd Conf. on Robotics for Challenging Environments*, 1996, pp. 15–21.

[14] R.R. Murphy, "Biomimetic search for urban search and rescue," in *Proc. IROS 2000*.

[15] R.R. Murphy, "Marsupial and shape-shifting robots for urban search and rescue," IEEE *Intell. Syst.*, vol. 15, no. 3, pp. 14–19, 2000.

[16] R.R. Murphy, J.G. Blitch, and J.L. Casper, "Robocup/AAAI urban search and rescue events: Reality and competition," *AI Mag.*, vol. 23, no. 1, pp. 37–42, 2002.

[17] R.R. Murphy and J.J. Martinez, "Lessons learned from the NSF REU site grant: Multiple autonomous mobile robots for search and rescue applications," in *Proc. Frontiers in Education*, 1997.

[18] D.A. Norman, "The problem of automation: Inappropriate feedback and interaction, not over-automation," *Philos. Trans. R. Soc. London, B*, vol. 327, pp. 585–593, 1990.

[19] M. Osuka, R.R. Murphy, and A. Schultz, "USAR competitions for physically situated robots," IEEE *Robot. Automat. Mag.*, vol. 9, pp. 26–33, Sept. 2002.

[20] D. Platt, "The use of robots as a search tool," *Fire Eng.*, vol. 155, no. 10, pp. 37–41, 2002.

[21] R.R. Murphy, J. Casper, M. Micire, and J. Hyams, "Assessment of the NIST standard test bed for urban search and rescue," in *Proc. NIST Workshop on Performance Metrics for Intelligent Systems*, 2000.

About the Author

Robin Roberson Murphy (IEEE Fellow) is the Raytheon Professor of Computer Science and Engineering at Texas A&M, Director of the Center for Robot-Assisted Search and Rescue and the Center for Emergency Informatics. She received a B.M.E. in mechanical engineering, a M.S. and Ph.D in computer science in 1980, 1989, and 1992, respectively, from Georgia Institute of Technology. She has over 150 publications on artificial intelligence, human-robot interaction, and robotics including the *Introduction to AI Robotics and Disaster Robotics*. Her insertion of tactical ground, air, and marine robots at 15 disasters including the 9/11 World Trade Center disaster, Hurricanes Katrina and Charley, and Fukushima has led to numerous professional awards, such as the Motohiro Kiso award and the AI Aube AUVSI award, as well as being declared an "Innovator in AI" by TIME, an "Alpha Geek" by WIRED Magazine, and one of the "Most Influential Women in Technology" by Fast Company. Dr. Murphy serves on several government and professional boards, including the Defense Science Board and the IEEE Robotics and Automation Society Administrative Committee. She co-founded the IEEE RAS Technical Committee on Safety Security and Rescue Robotics.



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CHAPTER NEWS



Key Chapter Update

In January 2014, IEEE-HKN launched the new “KEY CHAPTER” recognition. Each chapter is encouraged to complete the requirements to be named a “Key Chapter.” Participation and activity in the areas identified are the best practices of successful chapters.

Chapters that earn the Key Chapter recognition will be identified on the IEEE-HKN web site, be celebrated by their peers, and receive a special prize: an IEEE-HKN banner. The prize will be identified annually and promoted to each chapter along with the requirements.

Mandatory Requirements:

- Submits the Annual Chapter Report
- Submits the Notice of Election of Officers within one week of the election
- Submits the Induction paperwork either before or within one month of their induction ceremony

Fulfills two of the following requirements:

- Sends a representative to the Annual Student Leadership Conference
- Participates in one of the IEEE-HKN competitions, challenges or Founders Day-related activities
- Contributes workshop content to the IEEE-HKN Virtual Campus
- Completes an activity or program to reconnect with alumni
- Hosts a regional meeting of chapters geographically accessible

The Key Chapter recognition period will start on January 1 completing on December 31 of the same year. The ceremony to recognize Key Chapters will be held during the Annual Student Leadership Conference of the following year (example: Jan 1, 2014 – Dec 31, 2014 will be presented at the 2015 Student Leadership Conference).

How is your chapter doing? [Check the update.](#)



IEEE-HKN UPDATES



Welcome, Lambda Tau and Lambda Upsilon Chapters



The two newest chapters of IEEE-HKN: Lambda Upsilon (top) and Lambda Tau (bottom). Credit: Chris Mimms (Lambda Upsilon); Samuel Matos (Lambda Tau)

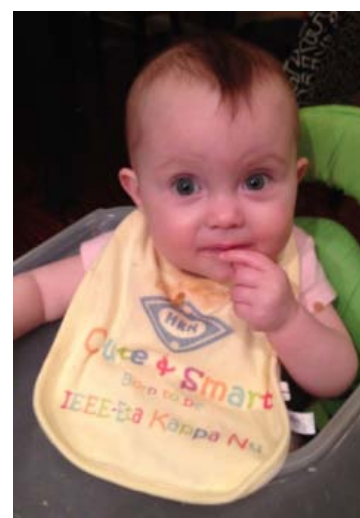
IEEE-HKN recently installed two new chapters: Lambda Upsilon at Embry-Riddle Aeronautical University, Daytona Beach and Lambda Tau at the University of Puerto Rico at Mayagüez. IEEE-HKN Board of Governors member Mark Law presided at the Lambda Upsilon installation; IEEE-HKN President John Orr led the Lambda Tau installation.

Combined, the two chapters installed more than 56 members with proven outstanding academic achievements, strong character and admirable attitude. In addition, the Lambda Tau chapter is the first IEEE-HKN chapter to be installed in Puerto Rico and only the second chapter to be installed in IEEE's Region 9.

Do you know college students or professors interested in starting an IEEE-HKN Chapter at their campus? Encourage them to reach out to IEEE-HKN Headquarters (info@hkn.org) to start the process.

Know a child destined for IEEE-HKN?

It's never too early to share your IEEE-HKN pride – email info@hkn.org to get a free baby bib for your child! Send a picture of your child wearing the IEEE-HKN baby bib and he or she may be included in a future issue of THE BRIDGE or included in IEEE-HKN social media content.



Ava, daughter of IEEE-HKN Board of Governors member Tim Kurzweg, shows the world that she is both "cute & smart" and "born to be IEEE-Eta Kappa Nu."

Credit: Tim Kurzweg



Visit the new IEEE-HKN website

Under the Society's long-time URL of www.hkn.org, IEEE-HKN recently launched a new, informative website to serve as the source for all of the

Society's news and resources. Visitors can access the latest news and updates, learn about the history of the Society and attain chapter forms and resources.

IEEE SOCIETY SPOTLIGHT



AEROSPACE AND ELECTRONIC SYSTEMS SOCIETY

IEEE offers more than 35 Societies that focus on technical information in specialized technology fields. Each issue of THE BRIDGE will feature an IEEE Society and include information on activities and information that can benefit IEEE-HKN members.

The Aerospace and Electronic Systems Society (AESS) within IEEE is a global network of engineers and scientists working in the electronic systems domain. Specifically, our members are deeply connected in the academia and industrial organizations that contribute to the design and implementation of various electronic systems including, but not limited to, satellites, radar, telemetry, spacecraft, defense, automatic test, and even mobile electronics.

The society hosts various meetings and conferences dedicated to the dissemination of fresh ideas and technologies along with providing a forum for networking. The majority of our conferences have student paper competitions and travel grant opportunities for students presenting papers.



*UAV design by AESS Student Chapter at Missouri University of Science and Technology.
Image Credit: David Erdos and Abraham Erdos*

Furthermore, the society provides several venues for authors to publish. Particularly for students, the AESS Magazine currently publishes "Student Highlight" articles. These short articles provide students with an opportunity to publish early in their career to an audience that otherwise might not see their contributions. In 2012, the "Student Research Highlight" was introduced as a new type of feature article that showcases research performed by a student pursuing an advanced degree. This year the "Student Project Highlight," which showcases an engineering/science project by graduate, undergraduate, or even a group of high school students, was introduced.

The AESS interacts directly with students through distinguished lectures and AESS-sponsored student projects. The AESS will often coordinate these distinguished lectures at universities in AESS conference locations.

Furthermore, the AESS sponsors student projects. For example, since 2006 the AESS has worked with Missouri University of Science and Technology to establish an unmanned aerial vehicle project (UAV) run by electrical engineering students. The students' search-and-rescue UAV recently competed in the Challenge-Outback Rescue competition in Australia. More information on this project can be found in the January/February 2014 edition of the *IEEE Potentials* magazine.

Overall, AESS provides students the opportunity to interact with peers with diverse interests in the electronic systems domain, particularly through publications, conferences venues, distinguished lectures, and student projects.

More information about the society can be found at <http://ieee-aess.org>. For students who would like to get involved with the AESS or publish an article as a student highlight, they should not hesitate to contact [John D. Glass](#) or [Richard A. Coogle](#), Associate Editors of Student Research, AESS Magazine.

MEMBER PROFILE



Keenan Johnson *Gamma Theta Chapter*



Keenan Johnson, from Jefferson City, MO, currently studies Computer Engineering with a minor in Computer Science at Missouri University of Science & Technology. In addition to his active involvement in Eta Kappa Nu, Keenan is active on several student design teams. He previously served as President for Miners In Space Student Design Team and led them in designing and conducting research on C.P.R. in micro-gravity aboard N.A.S.A.'s "Weightless Wonder" aircraft. He currently serves as a technical lead for Missouri S&T's Mars Rover Team Motherboard Squad.

After a year serving as a Resident Assistant, Keenan spent the summer of 2012 working at Adtran, Inc. in Huntsville, AL developing automated tests for telecommunication equipment. He then spent the spring and summer of 2013 at SpaceX, Inc. in Los Angeles, CA. There he spent 7 months working in the Launch & Test group developing and supporting software used to control and monitor the operation of all SpaceX vehicles including the Falcon 9 rocket and Dragon capsule.

Why did you choose to study computer engineering?

I like to create. I spent most of my childhood thinking up crazy inventions and attempting to build them. When I heard that I could get paid to do exactly that, I only had one question: "Where do I sign up?" I chose Computer Engineering because it allowed me to learn Electrical Engineering, Computer Science, and the interaction between the two. The two fields need each other to exist and I feel it is most interesting to understand and work with both.

What do you love about engineering?

I enjoy seeing my imagination realized in real life. The challenge of taking an idea from dream to reality has to be one of the most rewarding and challenging experiences around. I also enjoy that Engineering is a very team-centric field. I've had the opportunity to meet and work with some incredible people. Furthermore, the challenges are much easier and the successes more rewarding when experienced with a team.

What don't you like about engineering?

Engineers often become super specialized. They become the best at one very specific thing and end up doing exactly that for a large portion of their careers. I enjoy doing something different every day and believe that hyper-specialization is often a bad thing. I like to market myself as a problem solver, not necessarily an expert in a very specific thing. Unfortunately, in many companies, they are looking only for experts in very specific things.



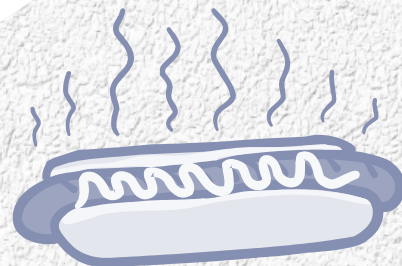
What is your dream job?

I like short design cycles, lots of project variety, and tough challenges. So, I think I would like to work as some sort of idea engineer working in a sort of R&D role. However, I also care deeply about what kind of work I do so that I am emotionally invested in what I am doing. Thus, I need to work on projects that are changing the world radically and for the better.

Finally, I'd like to be a professional musician at night. There are few things greater in the world than a room full of people dancing to your music.

Whom do you admire, and why?

I've always admired those who commit completely to a project or idea even though the outcome is uncertain. Those who risk everything to create a startup are some of the most visible examples. Dropping everything to pursue an idea is incredibly risky but shows a level of commitment I truly admire. Cory and Susan Lawrence are great examples of this. They are the owners of O'Doggy's in Rolla, MO (where I attend school). They both dropped their careers to open O'Doggy's, a local hot-dog stand. Starting a restaurant is hard work, especially when you don't have a building. However, the couple put their all into the business and have done extraordinarily well. They have just opened their first brick and mortar store, and continue to serve great hot dogs.



In what direction do you think that the engineering field is headed in the next 10 years?

I think that in the next 10 years, we will see technology decentralize in a big way. The past few millennia have created a centralized technology model. Manufacturing is done in large, central factories; data is stored and processed in huge, central server farms; etc. Technologies such as cheaply available 3D printing and pervasive computing are poised to disrupt the current system in a big, exciting way.

What is the most important thing you have learned in school?

In addition to the great technical skills I have picked up, the most important thing I have learned in school is how to lead myself. By that, I mean that I have learned how to maximize my talents, improve my weaknesses and be constantly aware of what and how I do things. The first step to leading others is leading yourself. School also provides lots of opportunities to have interesting cultural experiences. You live and work in close proximity with an incredibly diverse group of individuals. This gives you the chance to create interactions and opportunities that you may not get the chance to again. School also provides lots of opportunities to have interesting cultural experiences. You live and work in close proximity with an incredibly diverse group of individuals. This gives you the chance to create interactions and opportunities that you may not get the chance to again.

What advice would you give to other students entering college and considering studying your major?

Take risks and follow your passion. Always strive to reach the next level. Expect to fail often and learn from your failures. College provides you with an awesome support structure to do things you would have never thought possible. Take advantage of that.

Finish this sentence: "If I had more time, I would..."

.....follow my musical interests. Music is one of my great passions, and I wish I had more time to create and perform it.



MEMBER PROFILE



Cheryl B. Schrader *Gamma Theta Chapter*



Cheryl B. Schrader is the 21st chancellor in Missouri University of Science and Technology's nearly 150-year history and one of the few female engineers to ascend to the top leadership position of a college or university in the United States. A past president of the IEEE Control Systems Society, she continues to serve as IEEE representative of the ABET Engineering Accreditation Commission. Previously, Schrader was associate vice president for research at Boise State University and dean of Boise State's College of Engineering. She also undertook internships and consulting work with McDonnell Douglas Astronautics Co. and Chimera Research and served at the University of Texas at San Antonio and Rice University. Schrader did her undergraduate work at Valparaiso University and earned master of science and Ph.D. degrees in electrical engineering from the University of Notre Dame. Schrader's research background is in the area of systems and control. She has received several best paper awards; authored approximately 100 publications; and delivered more than 100 invited presentations and keynote addresses.

Passionate about increasing interest in STEM (science, technology, engineering and mathematics) education, Schrader's current research interests focus on creating and assessing innovative learning methods to help students of all ages succeed in the STEM areas. Schrader is a recipient of the Presidential Award for Excellence in Science, Mathematics and Engineering Mentoring from the White House; the IEEE Education Society Hewlett-Packard/Harriett B. Rigas Award; and the WebCT Exemplary Online Course Award. Additionally, she has been named one of Valparaiso University's Top 150 Most Influential People. She received the 2013 Distinguished Educator Award from the Electrical and Computer Engineering division of the American Society for Engineering Education. In 2014, she was named an IEEE Fellow in recognition of her leadership and contributions in engineering education.

Why did you choose to study the engineering field?

Growing up, I knew I was interested in math and science, and I considered becoming a schoolteacher. It was my dad who suggested I might enjoy engineering. I found the field appealed to me in many ways; I guess you could say I'm both a big-picture person and someone who has an eye for detail. In systems engineering, you get the best of both worlds. We get to see how complex components work together, how one part affects another and then optimize for best results overall.

What do you love about engineering?

I love the varied opportunities engineering affords, and I love the potential engineers have to make a difference in people's daily lives. Whether building better bridges, revolutionizing personal communications or bringing clean water to developing nations, engineers can uniquely improve the world we share. And once you're educated as an engineer, you can use your knowledge to make a difference in many areas, from social entrepreneurship to management.



What don't you like about engineering?

I dislike the lack of diversity in engineering. For decades we have worked to bring more women and underrepresented minorities into this field, and while we have made some progress, we haven't made enough. This is something we are actively engaged in at Missouri S&T, from ensuring school children participate in

engineering at a young age to creating an intentionally inclusive community on campus. Still, I think our field has a lot of work to do in this area. As Americans, our diversity is our strength, and our field should leverage this as well.

Whom do you admire, and why?

If I had to pick one person, it would be Mae Jemison. In 1992, she became the first African-American woman to fly in space, and she is an engineer, physician, professor, entrepreneur, dancer and actress. Dr. Jemison is someone who I admire for her tenacity to succeed, her confidence in her own abilities, and her blend of social concern and technical expertise. She is truly an inspiration to anyone who has overcome adversity to follow their dreams.

How has the engineering field changed since you started?

There is no doubt that engineering has become more global and strategic since I started in the field in the '80s. There was a time when engineers worked in silos and didn't keep tabs or pace with foreign innovation. Today, multi-national corporations expect and require that engineers work with international partners to maximize investment and outcomes. At Missouri S&T, our focus is on preparing students to be globally and culturally competent. Not only do we have many partnerships with international education institutions and global corporations, but we also welcome an increasingly international student body. In the past five years alone, we've seen an 80 percent increase in international students.

In what direction do you think that the engineering field is headed in the next 10 years?

I think there is a realization throughout this country that our economy is too reliant on the service sector and that a lack of manufacturing and investment in public infrastructure has hurt us. In the next 10 years, investments in the creativity and innovation of engineers will be essential to improving the economy and returning the U.S. to prosperity. For every one additional engineer employed in a state's workforce, state real gross domestic product increases by more than \$3 million.

What is the most important thing you have learned in the field?

I've learned that engineering is perhaps one of the most creative fields one can be engaged in. A common misperception is that engineering is dry and rote because, after all, to be successful one must be proficient in mathematics and science. These principles are our tools, but they do not in themselves create solutions to problems. It's the creativity of individuals and their diverse teams that lead to new breakthroughs and new solutions.

What advice would you give to recent graduates entering the field?

My advice is to seek mentors and be generous in giving your time to others. None of us start by knowing the ropes, and it's by building relationships that we can share knowledge and, ultimately, make a real difference in our field. At the same time, it's important to give back and help those who will follow in your footsteps.

If you were not in the engineering field, what would you be doing?

Truthfully, I can't imagine doing anything else. They say that engineering gets in your blood, and that's certainly the case for me. I love our field, and I love being able to facilitate the success of others in this great profession.

Finish this sentence: "If I had more time, I would..."

...Spend more time with my family! As a chancellor and a mom, I am always trying for a work-life balance. My husband and I make it work most days, but there are certainly times when I wish I could be in two places at once.



Mae Jemison
(Image Credit: NASA)

CHAPTER NEWS



Lambda Beta Chapter Teaches Circuit Construction to Local Third Graders

The Lambda Beta chapter at the University of California, Northridge recently visited a local elementary school, Emelita Academy Charter, and presented a workshop with several activities on how circuits work. Three students represented the chapter: Samuel Gaxiola, the president of the Lambda Beta chapter for the 2013-2014 school year, Erik Duarte, a new inductee, and Robert Morris, another new inductee. Approximately 40 third graders attended the workshop as well as three staff members (including the school principal).

The workshop began with a brief introduction to circuit construction. Topics discussed included how a power supply generates a current and how that current goes through a resistor to create a voltage. The chapter also talked about LEDs, as the workshop was comprised of making LEDs light up using a battery as a power supply.

Prior to making the trip to the elementary school, some of the chapter's officers and members, including Anjana Nonis, Eric Gamoning, and Kian Darian, soldered diodes to resistors in order to make sure that the diodes did not burn out quickly. The way this worked was also explained to the students, and soon after the presenters handed out a small kit consisting of batteries and the soldered diode-resistor combination. The students learned the different outcomes when the circuit was connected in series, in parallel, and with multiple power supplies.

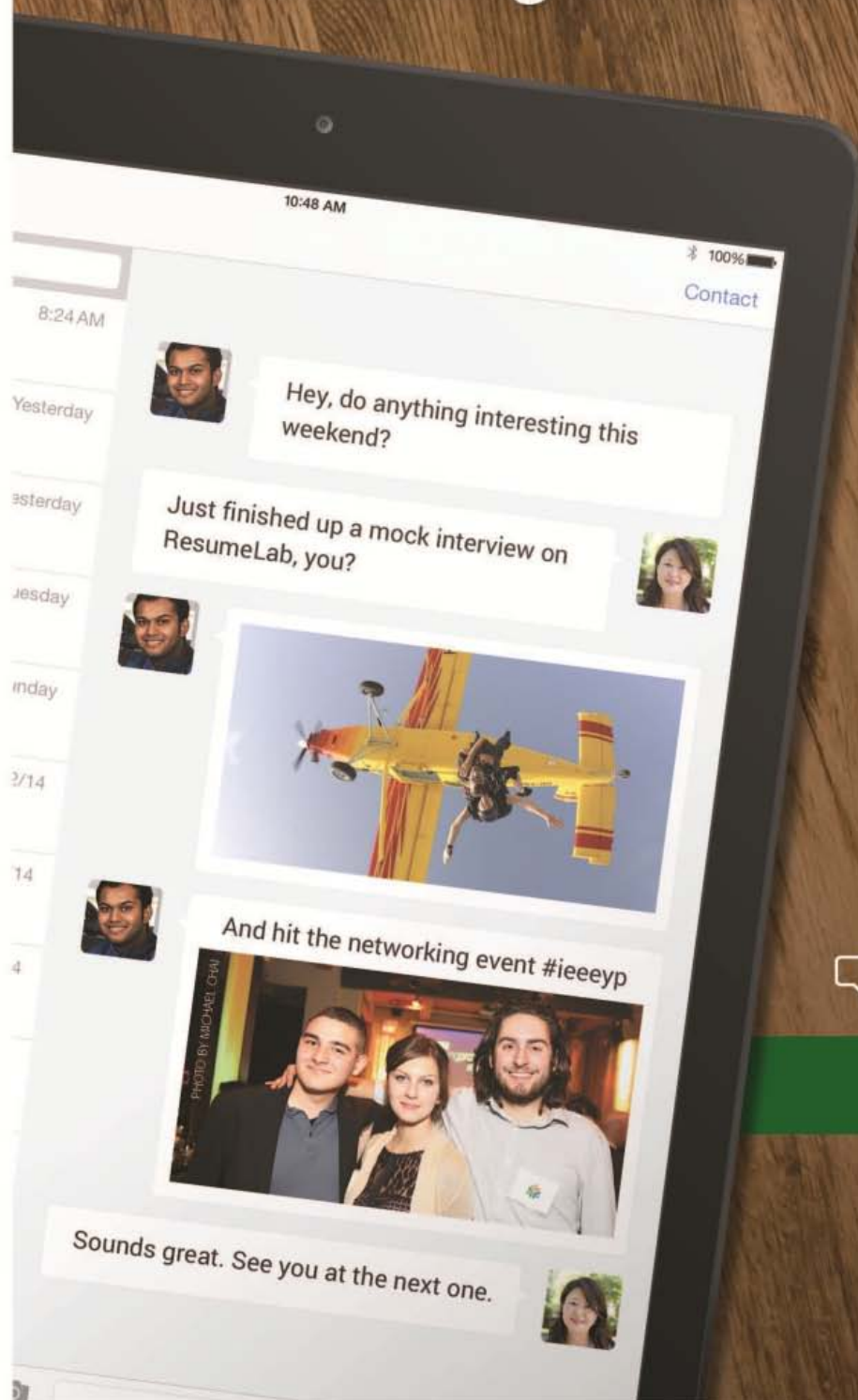
The students seemed to enjoy the workshop and picked up on the information quickly. Though they had no prior knowledge of how circuits work, this group of third graders used their intuition to predict several of the outcomes correctly. The school staff were extremely pleased with the outcome and asked the chapter to return. The chapter plans to visit and lead more challenging workshops that will further engage the students.



Robert Morris (top), Erik Duarte (middle) and Samuel Gaxiola (bottom) explain circuit construction to the third grade class at Emelita Charter.



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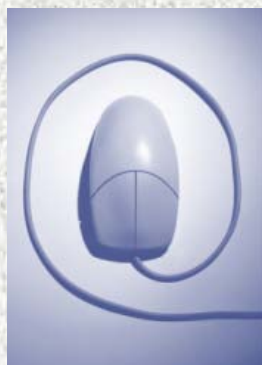
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