

# eeK2011

Electrical Engineering Kaleidoscope

Annual Research Review



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A Publication of the Electrical Engineering Department

University of Washington

# Welcome to eeK2011...



The year 2011 brings new excitement in research at UW EE. The department welcomes Professor Daniel Kirschen as the first holder of the Donald W. and Ruth Mary Close Professorship. As the energy needs in the U.S. escalate, it is timely that Professor Kirschen joins UW EE with his world-renowned expertise in smart grid, integration of renewable energies, electric power transmission, and economics of power systems. In addition to Kirschen, we are thrilled to have Associate Professor Josh Smith, and Assistant Professor Kai-Mei Fu join the department in 2011 as well.

Two of our faculty members were recently elected IEEE Fellows for 2011—Professors James Ritcey and Karl Böhringer. Ritcey is well known in wireless communications and radar/sonar signal processing, while Böhringer is known for his contributions in microelectromechanical systems and engineered self-assembly.

The kick-off celebration of the OpSIS (Optoelectronic Systems Integration in Silicon) Center occurred at the beginning of this year, and it provides new foundry services for silicon photonics. The Center is fully equipped with a state-of-the-art E-beam Lithography System, and Professor Michael Hochberg is the Director of this new Center.

And finally, this year's EEK edition continues to highlight the research projects of our top-notch undergraduate and graduate students. However, in addition to student research-driven articles, this issue also features some of the interesting entrepreneurial activities that our faculty and students are engaged in.

— LEUNG TSANG

Chair and Professor  
Department of Electrical Engineering

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## this issue...

### STUDENT RESEARCH

- Waveguides & Ring Resonators for Mid-infrared Wavelengths 3
- Control of Cellular Activity Using Light Through Quantum Dots 4
- Sensing Glucose on Contact Lenses 5
- Fluidic Self-Assembly of Millimeter Scale Thin Parts on Pre-programmed Substrate  
at Air-Water Interface 6
- Improving Cochlear Implants with Vocal Tract Resampling 7
- Hardware Acceleration of the Short Read Genome Mapping Problem 8
- Human Activity Recognition Using a 3D Camera 9
- Sensor Radios for Long-Range Communication 10
- SORA: A Platform for Wireless Experimentation 11
- Modeling the Emissions Consequences of Fossil Fuel Generator Ramping 12

### EE ENTREPRENEURS

- Introduction 13
- C4C Perspective 14
- Student Perspective 18
- Faculty Perspective 20

### FACULTY PAGES

- Faculty Listing 22
- New Faculty 24
- Haptics-Kinect Research 24



In keeping with our expressed goal of highlighting the department's interactions with the broader community and its' impact on society at large, the feature story of this issue focuses on some market-driven innovations by our faculty and students. This is a testament to the positive impacts of EE entrepreneurship on the other components of the academic ecosystem (notably, research and teaching), and the consequent impact on the regional economy. Translating research innovations into a product requires a supportive pipeline of complementary technical, business and market expertise, and involves key steps such as creating a business model and identifying potential customers/market segments, demonstrating feasibility with prototypes, identifying potential funding sources and marketing ideas.

The newly revamped Center for Commercialization (C4C) grew out of the previous Office of Technology Transfer with a new mandate for proactively identifying technology with potential for commercialization and is staffed with requisite in-house expertise to facilitate this process. Notable example of UWEE faculty/student led entrepreneurship is the venture-capital backed Physware, founded by Vikram Jandhyala, based on successful transitioning of cutting edge computational RF/EM algorithms developed in his ACE lab. C4C assisted with filing initial patents and finding early-stage funding; Jandhyala is currently recognized as one of C4C's inaugural Entrepreneurial Faculty Fellows and Physware employs former EE alumni.

Other ongoing examples of technology transition include Shwetak Patel's SNUPI—a low power, wirelessly enabled sensor node optimized for in-home monitoring —developed in his Ubicomp Laboratory, and Brian Otis' Bumblebee—another low power wireless enabled sensor platform oriented towards integration into implantable medical devices (pacemakers, glucose monitors et al) or non-invasive applications (attached to the skin for measuring muscular signals). In both cases, C4C has assisted with IP strategy and patent filings, as well finding funding for continued refinement of early stage technology.

— SUMIT ROY  
EEK Faculty Editor



# Waveguides & Ring Resonators for Mid-infrared Wavelengths

ALEXANDER SPOTT — Undergraduate Student (Physics)

The high index of refraction and low optical losses of silicon make it an ideal platform for controlling photons in an integrated, chip-scale system. It has historically been convenient for silicon photonic devices to operate at near-infrared (NIR) wavelengths (1310 and 1550 nm) in order to preserve compatibility with an existing fiber-optic infrastructure. However, there are many possible applications for chip-scale photonic systems at other wavelengths, particularly in the 2 – 20  $\mu\text{m}$  mid-infrared (MIR) wavelength region.

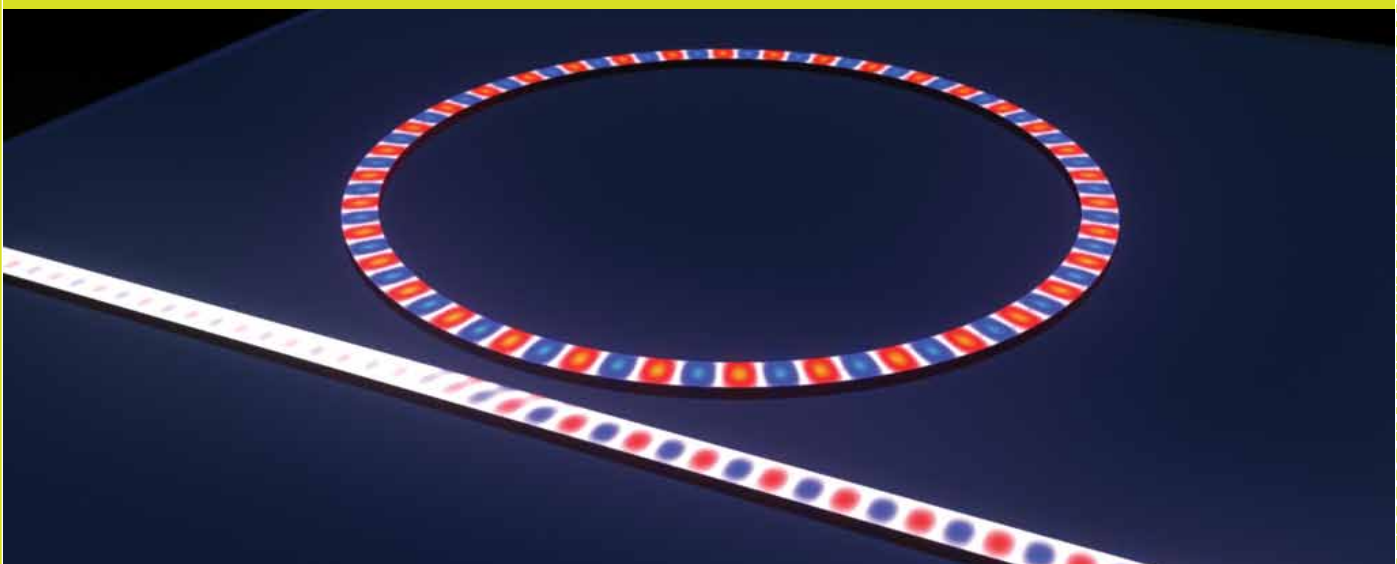
Silicon waveguides for MIR wavelengths have been proposed in a number of theoretical papers, but not experimentally demonstrated for wavelengths past around 3.5  $\mu\text{m}$  until recently. Silicon-on-insulator (SOI), the predominant material system for silicon photonics is unsuitable for work at MIR wavelengths primarily because the silicon dioxide insulating layer shows increasing optical losses at longer wavelengths. Researchers at UW EE's Nanophotonics Lab built their devices using silicon-on-sapphire (SOS), a material system used by the electronics industry as an alternative to SOI.

Waveguiding was first achieved with these devices in 2009, making the Nanophotonics Lab the first group in the world to demonstrate working waveguides at 4.5  $\mu\text{m}$ . Working with MIR wavelengths presents unique challenges due to the limited selection of optical equipment. Recent availability of affordable quantum cascade lasers, high-

speed detectors, and fibers has made MIR photonics a promising field.

Low loss waveguides enable the construction of ring resonator devices, a fundamental building block for photonics systems in the NIR used in a number of applications including biosensing, modulation, and wavelength conversion. The first working ring resonators for 5.4 – 5.6  $\mu\text{m}$  were designed, built and recently demonstrated by the Nanophotonics Lab.

MIR wavelengths have found applications in thermal imaging as well as chemical bond spectroscopy and biosensing. The ability to manipulate MIR light on-chip will allow control of the MIR light with nanometer precision, opening up the opportunity to create new, complex systems that utilize these wavelengths. [eeK11](#)



A three-dimensional rendering of a ring resonator device shows the optical mode propagating through the waveguide.

FACULTY ADVISOR: Michael Hochberg

RESEARCH AREA: Nanophotonics

GRANT/FUNDING SOURCE: The NSF STC MDITR Center, the Mary Gates Endowment, the Washington NASA Space Grant Consortium, & the PECASE Award



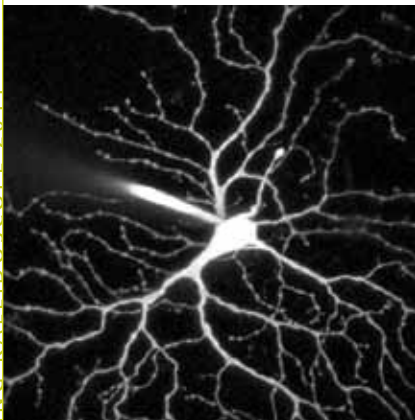
# Control of Cellular Activity Using Light Through Quantum Dots

KATHERINE LUGO OBANDO — Graduate Student (EE)

Electrical signals in the brain govern the complexity of the human body and mind. Remote switching of these signals will answer questions about sensory, motor and behavioral events, which fundamentally control our health.

Quantum Dots (QDs) are semiconductor nanoparticles that have different applications in optical devices, photodetectors and solar cells because of its high quantum efficiency, and in fluorescence imaging because of its size-dependable emission and surface chemistry variation. Stimulating cells using light is non-invasive, but most photostimulation approaches require genetic manipulation to introduce foreign light-sensitive protein channels, or conductive substrates, which are not suitable for in-vivo applications. This research proposes a new approach for stimulating cells using light through QDs.

When excited by light, QDs present an electron-hole separation generating a dipole-induced electric field. Interaction of this field with the cell membrane (CM) can perturb the CM potential to evoke action potentials, active electrical signals, or hyperpolarize the cell and turn its potential more negative which is associated with a passive electrical response.



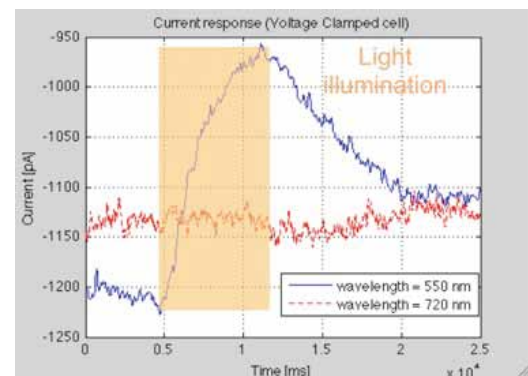
A neuron image with an electrode of the patch-clamp technique coming from the left.

In the proof-of-concept experiments, CdSe QDs with an emission peak of 640 nm wavelength and an absorbance from UV to orange are used to coat glass micropipettes utilized in patch-clamp recording. Cultured cortical neurons are stimulated by placing a CdSe QD-coated probe close to the CM. A mercury lamp source filtered to 550 nm, excitable wavelength to CdSe QDs, and 720 nm, non-excitable wavelength to CdSe QDs, illuminate the cell-QD probe system to evidence the effect of QDs. When QDs are excited



A fluorescence image of a micropipette coated with CdSe QDs.

A patch-clamp recording of the CdSe QD-cell system on ionic currents. Light excitation: 550 nm and 720 nm.



through the appropriate wavelength, the inward current of the CM changes, which perturbs the electrochemical equilibrium of the CM.

The preliminary experiments using coated glass micropipettes demonstrate the ability of QDs to perturbate the CM potential. In the future, QDs surface chemistry can be modified for direct attachment to biological particles using linker molecules such as avidin, antibodies or enzymes that specifically bind acceptors located on the CM.

In addition to controlling QD-cell systems better, and investigating direct attachment of QDs to cells using linker molecules, further research will explore biocompatible Si QDs for the applications. Studying cellular activity using light through QDs will give better understanding of how billions of circuits in the brain work and how these are linked with higher-order brain functions. [eeK11](#)



# Sensing Glucose on Contact Lenses

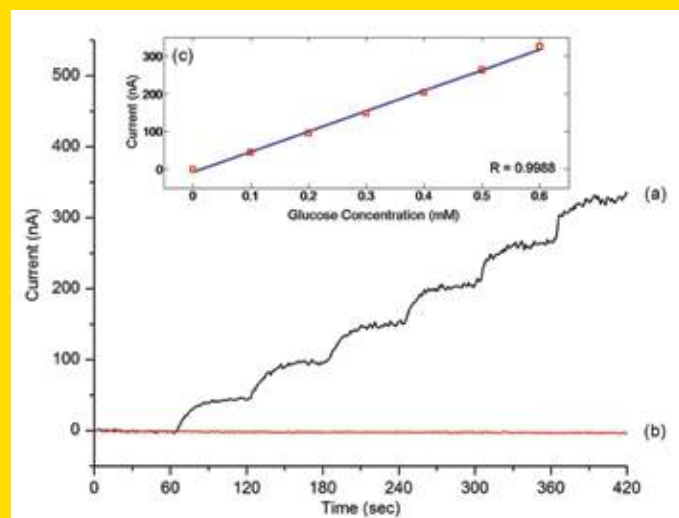
HUANFEN YAO — Graduate Student (EE)

Similar to blood, liquid in the human eye contains various analytes of interest for medical applications such as glucose, lactate and proteins. These chemicals can be used as markers to indicate human physiological and metabolic levels. In contrast to blood and tissue fluid, tear fluid is directly accessible and can provide a unique method to develop an interface between the sensors and the human body. By building a safe, comfortable contact lens that could also sample, analyze and wirelessly transmit results, it could be used as a new tool for non-invasive continuous health monitoring.

This research focuses on developing a glucose sensor on a contact lens. The sensor can continuously monitor human glucose levels in the tear film based on electrochemical sensing. The sensor can achieve high sensitivity, good reliability and interference rejection for other chemicals, such as ascorbic acid, lactate and urea. Combined with the relevant control electronics, antennas and data communication systems, the contact lens sensor will provide a creative way to monitor human health on a daily basis. The glucose sensor is an amperometric sensor, fabricated using modern microfabrication techniques. Prior to combining the circuitry with other electronics, the sensor will be evaluated using a potentiostat, characterized using low glucose levels similar to those in the tear film, and tested for an interference rejection effect.



The completed sensor on a contact lens.



A typical amperometric response and calibration curve of the sensor.

This project aims to build a functional contact lens complete with sensors, antennas, control electronics and data communication modules for the continuous monitoring of human health. The goal is to develop a contact lens can be worn safely and comfortably throughout the day similar to a conventional contact lens. eeK11

FACULTY ADVISOR: Babak Parviz

COLLABORATORS: Associate Professor Tueng Shen (Ophthalmology), & Assistant Professor Brian Otis (EE)

RESEARCH AREA: Devices

GRANT/FUNDING SOURCE: National Science Foundation



# Fluidic Self-Assembly of Millimeter Scale Thin Parts on Pre-programmed Substrate at Air-Water Interface

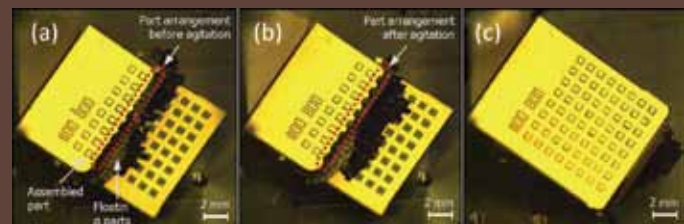
KWANG SOON PARK — Graduate Student (EE)

Fluidic self-assembly (FSA) is a promising alternative to conventional serial pick-and-place assembly. The serial pick-and-place mechanical assembly enables a high yield. For small size parts, however, it becomes slow and difficult to control due to undesirable strong stiction forces.

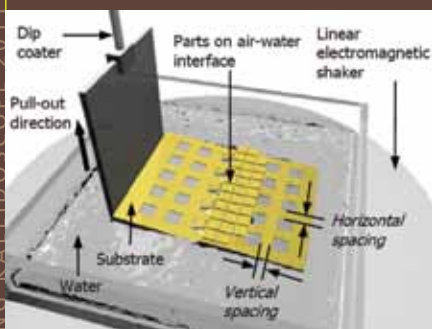
Therefore, conventional pick-and-place assembly of large numbers of small and thin parts becomes costly and FSA is preferred. Previous FSA systems have used various driving forces such as gravity, surface tension, electrostatic or electromagnetic force and often require adhesives, liquid solder or two different liquids. Unfortunately, these methods have lower yield compared to pick-and-place assembly due to their stochastic nature.

Researchers at the UW EE MEMS Laboratory have developed a novel method to achieve high yield (100%) assembly of millimeter-scale thin silicon parts from air-water interface using surface programmable template substrate and specific surface waves. The silicon-oxide binding sites are hydrophilic and the self-assembled monolayer (SAM) coated Au area is hydrophobic, which provides the high contrast between their surface tension. The substrate is tilted at a certain angle and thin parts are distributed at the air-water interface and move toward the substrate due to the convex meniscus.

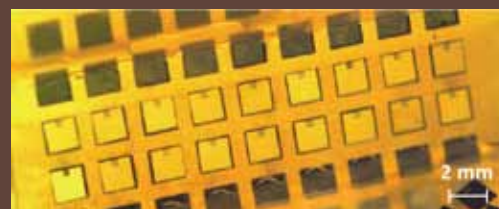
There can be multiple or no parts occupying one binding site, which can result in assembly failure. To assemble only one part on one binding site, one-to-one part-to-site registration is needed. This can be achieved by applying vertical agitation. The parts on the hydrophobic non-binding site area will be repelled away because they don't have enough capillary force to overcome the agitation. Thus, parts can be assembled only on the hydrophilic binding sites by pulling up the substrate.



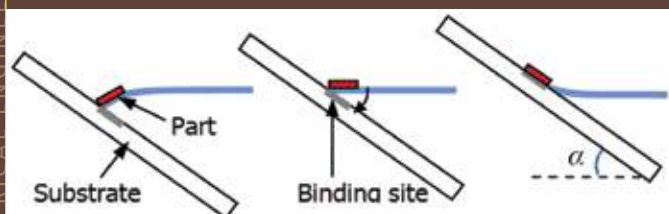
Parts rearrangement by agitation. Specific surface wave (80 Hz / 1.4 g) is also applied at every row to achieve one-to-one part-to-substrate registration ((a) and (b)), which enables 100% yield (c).



The experimental setup consists of a water container, linear electromagnetic vibration table, dip coater with affixed substrate and parts floating at the air-water interface.



The assembly result of orientation-specific assembly. All parts are oriented in one direction due to the magnetic field and nickel pattern on parts (2000×2000×100  $\mu\text{m}^3$ ).



For successful assembly, the parts go through three steps: approach, flat surface and assembly.

By integrating electronic, optical and fluidic components on to a variety of substrates using self-assembly, powerful microstructures that cannot be fabricated on the same wafer due to an incompatible fabrication process can now be built. Further research will develop an orientation-specific assembly to achieve greater flexibility for the types of devices to ensure electrical functionality. [eeK11](#)



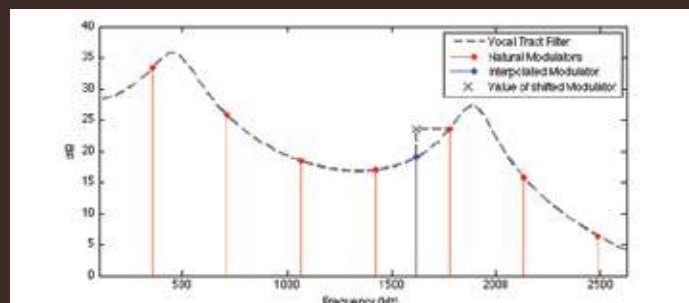
# Improving Cochlear Implants With Vocal Tract Resampling

ELLIOT SABA — Undergraduate Student (EE)

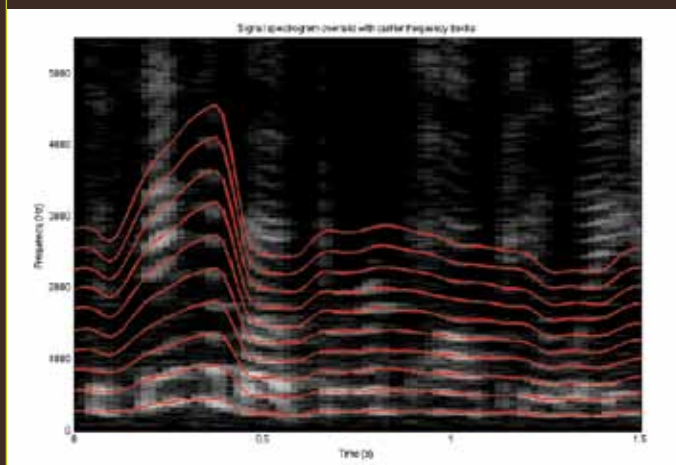
Cochlear implants perceive sound for victims of profound hearing loss by connecting electrodes directly to the auditory nerve endings in the ear. State-of-the-art cochlear implant systems use a form of demodulation that can be improved upon for better speech and melodic recognition in cochlear implant users. Combining this form of demodulation with a novel vocal tract filter resampling technique allows for pitch-invariant representations of a speaker's vocal tract, and a more robust cochlear implant processing.

Each electrode in a cochlear implant excites nerve endings in the ear with the amplitude envelopes of the spectral energy contained within a subband of frequencies. Traditionally, incoherent demodulation is used to find these envelopes by taking the magnitude of the Hilbert transform of each subband. This results in modulators that cannot be remodulated without severe distortion. Using coherent methods, the harmonic nature of signals can be communicated to the brain by remodulating the envelopes with a carrier set at the fundamental frequency of the input signal. First, a strong harmonic is found, and then it is shifted down to baseband, filtered, and re-shifted up to the fundamental before stimulating the nerve endings with it. However, this approach does not address the issue that modulator magnitudes are a function of time and frequency, and must be interpolated to match their location in frequency to avoid distortion.

Exploiting the fact that the harmonics of speech evenly sample the vocal tract filter, the frequency response of this filter can be resampled, yielding a pitch-invariant reconstruction of the vocal tract. Therefore, appropriate magnitudes can be generated for each modulator at any point in frequency, while still retaining the benefits of coherent demodulation.



A cross-section of frequency showing the even spacing of harmonics, allowing approximate reconstruction of the vocal tract filter and resampling of it at any point without magnitude distortion.



A spectrogram of speech, highlighting the harmonics that sample the vocal tract filter, and will be interpolated.

This interpolation of modulator magnitudes will increase speech recognition for users of cochlear implants utilizing already-deployed technology, and will broaden the pool of potential users, including those that require pitch-contour information (i.e. Chinese). Melodic recognition may also improve, opening the possibility for musical appreciation in cochlear implant users.

The entire project aims to build a functional contact lens complete with sensors, antennas, control electronics and data communication modules for the continuous monitoring of human health. The goal is to develop a contact lens can be worn safely and comfortably throughout the day similar to a conventional contact lens. [eeK11](#)

**FACULTY ADVISOR:** Les Atlas

**COLLABORATORS:** Graduate Students Pascal Clark & Xing Li

**RESEARCH AREA:** Digital Signal Processing

**GRANT/FUNDING SOURCE:** Mary Gates Research Scholarship, Air Force Office of Scientific Research



# Hardware Acceleration of the Short Read Genome Mapping Problem

MARIA KIM & COREY OLSON — Graduate Student (EE)

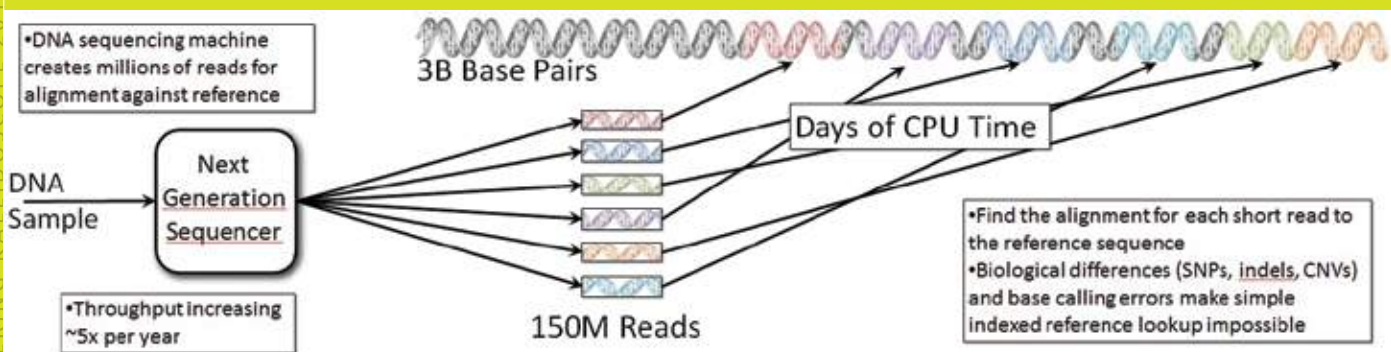
The Human Genome Project resulted in the compilation of a known reference human DNA sequence, which is now used by research institutions to study the biological causes of many diseases. The DNA strands are read by next-generation sequencing machines by replicating the DNA sequence, splicing the strand randomly, and then reading the short sequences of base pairs in a massively parallel manner. The throughput in this process has been on a “super-Moore’s Law curve” for the past few years, and the alignment of the so-called “short reads” to the reference sequence is quickly becoming the bottleneck in this genomic research.

The Smith Waterman algorithm is used for the alignment portion of DNA mapping because it can compare the reference and read sequences, base by base, in order to reveal how likely the read is to match the reference. In addition, the algorithm’s scoring system takes into consideration the issues with alignment, which includes insertions, deletions, and polymorphisms. However, the Smith Waterman algorithm is computationally expensive. Researchers at UW EE’s ACME Lab have developed a few solutions to accelerate the alignment process.

First, the Field Programmable Gate Array (FPGA) is used as the hardware platform because the structure of the

device is able to accelerate the algorithm significantly. The FPGA is reconfigurable hardware composed of multiple computation blocks. These blocks can perform computations in parallel, which allows for a computation and power efficient system.

An additional strategy used to optimize this system is an algorithm that takes shortcuts by using Candidate Alignment Locations (CALs) for the read. This results in running the Smith Waterman algorithm exclusively on the read and its CALs, instead of the entire three billion base pair reference sequence, which reduces the number of computations considerably.



Next-generation sequencing machines produce hundreds of millions of short DNA sequences (50 - 100 base pairs), which must be aligned to the three billion base pair reference genome. This data intensive process can be accomplished in several days by software or a matter of minutes with a hardware accelerator.

This research will decrease the time to map an individual’s DNA from approximately a week via software to a matter of minutes via hardware. This will allow researchers to identify variations in the DNA sequence, and potentially lead to new medications targeting DNA as the underlying cause of a disease. [eeK11](#)

FACULTY ADVISORS: Scott Hauck, & Carl Ebeling & Larry Ruzzo (CSE)

COLLABORATORS: Undergraduate Students Cooper Clauson (EE & CSE) & Boris Kogon (CSE), & Mark Seligman (Rapid Biologics)

RESEARCH AREA: Computer Architecture

GRANT/FUNDING SOURCE: Pico Computing & the Washington Technology Center



# Human Activity Recognition Using a 3D Camera

HAOWEI LIU — Graduate Student (EE)

Recognizing and analyzing human activities, especially those involving object manipulation, is a central problem of computer vision. The types of activities to monitor can range from maintenance sequences for factory workers to medication regimens for elders.

For example, it could be useful to confirm that a particular tool was used correctly on the factory floor or that an elder opened a pill box and used its contents. Conventional vision-based approaches, based purely on interpreting color images, are brittle due to lighting changes, shadows and color proximity among objects. The recent past has seen the advent of active depth cameras, which return the depth of each pixel in the scene with cm-level precision robustly under most illuminating settings. This work approaches the problem using such a camera.

The 3D camera provides synchronized 640x480 color and depth images at 30 frames per second. Given an incoming depth image, the background depth frame is subtracted from it to localize the moving foreground object (i.e. the human body). With color frames, the above scheme fails because color is sensitive to varying illumination effects. However, other than a small amount of sensor noise, this scheme works with depth images because changes in depth are generally due to the structural change (i.e. the presence of foreground objects).



Original color/depth images from the camera. Lighter shades are closer to the camera. Black pixels are sensor failures.



Given the detected human body, regions corresponding to arms and torso are parsed. Accurate size information available from the 3D camera is exploited to identify body parts. In particular, body parts have distinctive size statistics (i.e. the torso is usually wider than the arms), and simple local size information can be used to detect different body parts even in the presence of self occlusion. Given an arm localized in this manner, a skin color detector can be applied to detect the hand and then segment out the object. The hand location and object mask are sent to a classifier for joint object and activity recognition. This method achieves 82%/74% precision/recall on a large dataset.



This approach localizes and parses the human body into torso (blue) and arm (red).

A segmented object.



An effective approach has been developed for recognizing object-manipulation based activities in everyday life by extensive use of depth cues. In conclusion, the use of depth information available from inexpensive modern 3D cameras can substantially improve the performance of a video-based activity recognition system. [eeK11](#)

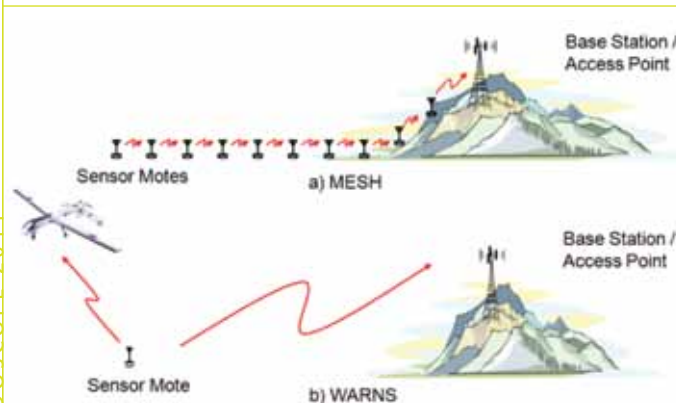


# Sensor Radios for Long-Range Communication

WILL WESSON, VENU BHAGAVATULA & POHAN YANG — Graduate Students (EE)

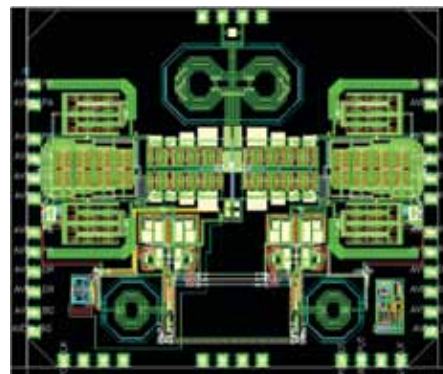
The conventional approach towards communicating sensor information over long distances is through a series of short-range wireless links, configured in a mesh network.

Under ideal conditions, using numerous short-range hops to communicate with a distant base station provides an energy/bit optimized link. However, issues related to network self-assembly, substantial infrastructure investment for low-spatial density applications, and limited use for highly mobile wide-ranging sensor applications set practical limits on mesh networks. This work explores an alternate approach called a Wide Area Radio Network for Sensor (WARNS) communication which utilizes a single-hop transmission for direct access from a sensor node to a base station using standards-based signal modulation. By directly transmitting data several kilometers, existing cellular, WiFi and PAN infrastructure can be accessed to deliver sensor information.



a) Sensor communication using a conventional mesh network. b) Single-hop, WARNS transmission.

sensor devices in standards-based systems, this work focuses on the most challenging aspects of the hardware design – the transmitter and power amplifier. To benchmark several new concepts which specifically tailor the sensor transmitter for long-range, performance commensurate with a common world-wide cellular standard, GSM, is targeted. The single-chip CMOS transmitter utilizes a regulatorless power amplifier which dynamically scales the load-impedance. This device is implemented in a 90nm TSMC process and is intended for use with conventional solar-cells, which fit in a form-factor of less than  $1\text{cm}^3$ . The PA will deliver one watt to the antenna at 1.9GHz, making it compatible with sensor communication up to five kilometers. The ultimate vision of this work is to first demonstrate range and then seek chip-level architectures which are highly programmable with multi-standard capability. This would allow a sensor device to be placed anywhere in an urban environment and seek available base stations for communication (this concept is referred to as “network scavenging”).



WARNS 90nm TSMC PA. Die size 1.8mm x 1.8mm.

An explicit goal of WARNS is to enable long-distance, single-hop transmission from a sensor node directly to existing wireless infrastructure. Another goal is to retain all of the properties (low-cost, small-factor, and autonomous operation in the field using conventional energy scavenging devices) associated with short-range wireless radios while allowing it to operate for years at a time. Although this research is multidisciplinary, involving topics from electromagnetics to more efficient methods of networking

The design will be fabricated in early 2011, after which a demonstration platform, with solar cells will be constructed. This device has potential to transform the way sensor devices communicate in the field, providing instant coverage for applications including environmental monitoring, homeland security and military barrier coverage. Subsequent research will focus on addressing issues related to the high-path loss of near-ground transmission in addition to more secure and efficient networking methods. [eeK11](#)



# SORA: A Platform for Wireless Experimentation

ZIXIA HU & HAMED FIROOZ — Graduate Students (EE); AMIR AGHDASI — Undergraduate Student (EE)

Microsoft Research Software Radio (Sora) is a novel software radio platform with full programmability on commodity PC architectures. Sora combines the performance and fidelity of hardware software defined radio (SDR) platforms with the programmability and flexibility of general-purpose processors (GPP).

Sora uses both hardware and software techniques to address the challenges of using PC architectures for high-speed SDR. Microsoft does not make any RF boards, but recommends that the Sora board is embedded into a Quad-Core-CPU PC with XP operating system, and broadcasts the signals on 2.4 GHz and 5 GHz. Typically, the PHY and MAC layer processing of wireless communication systems is implemented on Field Programmable Gate Array (FPGA) or Application Specific Integrated Circuits (ASIC) chips, which leads to limited user control/programmability for experimentation aimed at validating systems-level objectives. The Sora platform is a significant advance due to the resulting convenience for experimentation, since the platform is completely software-based and runs on a low-cost commodity PC. This advantage is especially convenient for research groups in academia.

etc., and has already been successfully tested on the Sora board. The system allows high-quality digital audio signals to be transmitted within an FM radio channel without causing any interference.



Real-time data transmission and reception over the air has been realized between a pair of PCs with the Sora boards, acting as transmitter and receiver, respectively.



A Sora board embedded into a Quad-Core-CPU PC with XP operating system, which broadcasts the signals on 2.4 GHz and 5 GHz.

Researchers from UW EE's Fundamentals of Networking Lab (FunLab) are working on demonstrating the concepts of efficient wireless relaying. The set-up consists of two sources which are not in transmission range of each other and a relay node in between. The goal is to show increased throughput by exploiting network coding at the MAC layer of the nodes. Theoretical results show that by simple XOR operation at the MAC layer, the number of time slots needed to exchange data can be decreased. The MAC layers have already been modified accordingly such that nodes are able to distinguish network coding packets, perform XOR operation and extract desired information. eeK11

Taking advantage of the programmability of the Sora platform, graduate students at UW EE's Wireless Information Technology Lab are implementing a newly designed wireless transmission system on the SDR. The project titled, "High Definition Digital Radio Broadcasting," covers the entire PHY layer including OFDM, channel coding, synchronization, frequency hopping, channel estimation,

FACULTY ADVISOR: Hui Liu & Sumit Roy

RESEARCH AREA: Wireless Communications

GRANT/FUNDING SOURCE: National Science Foundation & Donation by Microsoft Corp.



# Modeling the Emissions Consequences of Fossil Fuel Generator Ramping

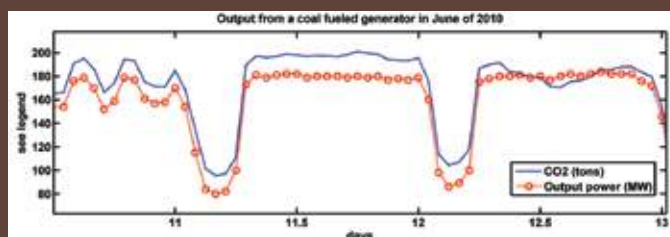
KAREN STUDARUS — Graduate Student (EE)

Researchers in the UW EE's Wind Integration Research Lab (WIRL) are exploring and modeling power system operation with high levels of wind power and other stochastic generation.

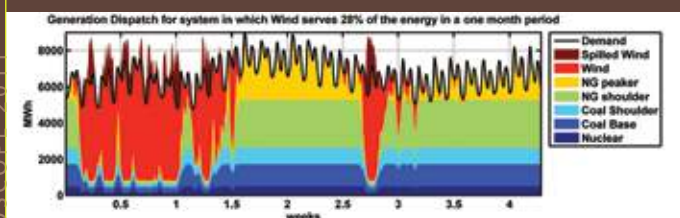
Renewable energy sources and demand response offer the promise of reduced air polluting emissions ( $\text{CO}_2$ ,  $\text{NO}_x$ ,  $\text{SO}_x$  and particulate). However, the high variability and lower predictability of these increasingly utilized sources causes the power system to operate as never before; fossil-fuel burning thermal plants now have a financial incentive to operate at less than full power and to ramp quickly in response to sudden mismatches in load and available generation.

These new operating regimes challenge the appropriateness of conventional policies. As the most mature among stochastic renewable technologies, wind power is the obvious first choice for close analysis of integration. Wind events (like big gusts and lulls) are primary drivers of thermal plant cycling events in regions that rely heavily on wind power. WIRL examines the consequences of large quantities of wind (actual, planned and theoretical) in diverse regional power systems.

Using statistical analysis of observed emissions from all thermal plants in the United States, some of WIRL's work explores whether currently employed models of thermal plant emissions, developed for multi-objective optimal generation dispatch in the 1980's, sufficiently capture transients induced by high variance operation.



The power output of a coal generator with corresponding observed  $\text{CO}_2$  emissions. This figure details one example among  $1.5 \times 10^5$  ramping events under consideration (data source: US Department of Energy).



A simulated cost minimizing example system dispatch is shown with 30% wind energy penetration. In response to a rapid increase in wind velocity, some wind power is "spilled," natural gas fueled units respond quickly by shutting down, base load generation reduces output, and excess energy is sold to neighboring markets (data source: Bonneville Power Administration).

An accurate and concise characterization of the emissions consequences of novel power system operating regimes will inform power system operation, energy market design, and environmental policy. An emissions minimizing dispatch can only be as good as its underlying emissions model. [eeK11](#)

# From UW EE Labs to Market

## 21st Century Entrepreneurship – A Tangible Impact

UW EE students and faculty are actively engaged in turning innovative ideas and technologies developed in the laboratory into tangible products and services for consumers. By making commercially relevant innovation accessible to society and the marketplace, the UW EE community is profoundly contributing to new consumer products, energy savings devices, new healthcare and transportation options, as well as communication, information and software products. This transformation from laboratory and computational prototypes to products is a core aspect of electrical engineering practice. At UW EE, it provides an opportunity for engineering education at its best. The articles that follow provide a sampling of such entrepreneurial activities occurring at UW EE from the perspectives of student, faculty and the UW Center for Commercialization.

# C4C Guides EE Innovators Along the Path to Commercialization

Assistant Professor Shwetak Patel's Ubicomp research lab technology could enable a new class of low-cost and easy-to-deploy sensing systems for homes. If this system gets to the market, it could revolutionize home monitoring, alerting homeowners to humidity or moisture in the attic, plumbing that could spring a leak, or the presence of carbon monoxide.

Professor Patel and UW researchers like him in hundreds of labs across campus are making extraordinary discoveries that could positively impact millions of people. The process of bringing an innovation to market can be as equally rewarding and fun as carrying out the research behind it—whether the technology is licensed to an existing business or start-up. Entrepreneurial researchers work with UW's Center for Commercialization (C4C) on market analysis, patent searches, and management of intellectual property. Where there's a decision to launch a startup, they participate in business plan development, recruitment of management, and capital formation.

Patel's past venture on residential energy monitoring led to a successful acquisition of his startup company in 2010. He has been engaged with C4C for over a year, most recently supported by C4C Technology Manager Mike Clarke. By engaging with C4C at the earliest stages of his research, Patel has enabled C4C to funnel more resources—commercialization grants and expertise—for his projects.

The recently developed home sensing technology, nicknamed SNUPI (Sensor Notes Utilizing Powerline Infrastructure), showed early promise for the commercial market, so C4C, strategizing with Patel and the other inventors, filed a patent application. SNUPI inventors include Patel's advisee in the Ubicomp lab, EE PhD student Gabe Cohn, and their collaborators in the Wireless Sensing Lab, EE Assistant Professor Brian Otis and his PhD advisee Jagdish Pandey.

Technology Manager Clarke worked with Patel to secure a Commercialization Gap Fund (CGF) grant this past fall—funded by C4C and the Washington Research Foundation (WRF)—for \$50,000 to build a demonstration unit that could help attract private investors. During the grant process, Patel and his team also received advice on market applications from C4C Entrepreneurs-in-Residence (EIRs) Ken Meyer, a technology industry expert with 20 years of experience leading both start-up and Fortune 100 companies, and Henry Berg, a director with A3 Alliance, which makes convertible debt investments in start-up and early-stage technology companies.



SNUPI (Sensor Notes Utilizing Powerline Infrastructure).

"Ultra low-power wireless sensor networking is an area where we are focusing C4C's resources and developing a strong IP portfolio," said Clarke. "SNUPI is a remarkable achievement in this space. It optimizes the size, cost, and power of the sensing node for real-world commercial usability, while taking advantage of existing home wiring as a receiving antenna and transmission line to extend its effective communication range."

With backing from C4C, SNUPI is on the road to being the focus of a start-up company that positions the technology as a replacement for wired or battery-powered in-home fire alarms and other sensors. An advantage over current products is that SNUPI-based systems can function for 20 years or more without the need to change batteries. Insurance companies should have great interest in these products, as they receive large claims as a result of fires, water damage if a refrigerator hose breaks, or a leaky roof that leads to a mold problem in the attic. SNUPI has already generated media attention in publications such as MIT's *Technology Review*.

The UW Center for Commercialization (C4C) is committed to UW research innovations, enabling the introduction of new or advances in existing products, services, diagnostics, and therapies. C4C has commercialized more than 100 projects and spinout companies since 2005, including awarding over \$4 million in grants for UW researchers.

## C4C Guides Innovations from Lab to Market

Technology Manager Mike Clarke is a member of C4C's 50-person team. C4C Technology Managers are the primary contact for UW researchers, responsible for directing technology-specific resources to each project. UW researchers are experts in their research area, while C4C is UW's proactive service organization, providing leadership and support in the movement of research into products available to consumers and patients.

Led by Linden Rhoads, UW Vice Provost and a technology entrepreneur, C4C engages with researchers as early as possible—months or even years before a technology disclosure. C4C staff proactively build connections with researchers to understand their work and brainstorm on potential applications. Early engagement means C4C can consult industry experts on industry needs, identify potential commercial partners, map out the competitive landscape, provide early intellectual property analyses, and more. The result? More commercially relevant innovations in the UW commercialization pipeline.

## Partnering with C4C

C4C's programs provide assessment of commercialization potential and guidance on project development. The first step is the evaluation of the opportunity. At an initial meeting, the Technology Manager discusses the research and begins working with the research team to establish whether there is commercialization potential, asking questions such as:

- What is the technology and its stage of development?
- How defensible is the IP position?
- How large are the applicable market(s)?
- Who is the competition?
- Is there a viable go-to-market strategy?

If the innovation seems promising, C4C experts work with the researcher to pursue IP and engage with a commercialization team assigned to see the innovation move from lab to application. Assistance can include leadership or guidance from C4C's New Ventures Program, created specifically to support UW start-ups. New Ventures connects researchers with Entrepreneurs-in-Residence (EIRs), local business executives, attorneys, and investors for advice, education, and mentorship.

Other collaboration between EE and C4C include Assistant Professor Brian Otis' emerging low-power sensing technology and the late-stage commercialization of Professor Vikram Jandhyala's high-speed solutions that enhance modeling and design of semiconductors.

## From Raw Research to IP Protection

If a researcher's innovation is potentially patentable, the Technology Manager directs the C4C IP Management group to perform patentability search and analysis. Where the decision is to proceed, C4C will prepare, file, and prosecute the eventual patent application. The likelihood of significant commercial opportunity is a major factor in deciding where to seek patent protection. C4C's patenting committee (involving other Technology Managers and IP Management staff) examines all relevant data and makes final determinations as to whether the technology meets the required criteria. In many cases, the finding is that additional experiments and data are needed. C4C will advise researchers on meeting these requirements before filing for patent protection.

## The Bumblebee: From Lab to Market to Next Big Technology Wave

In the world of wireless sensors, size matters—and for many applications, the tinier the better. On a quest for the ultra-small and lightweight, Assistant Professor Brian Otis and his students have designed a low-power wireless sensor called the Bumblebee, which is more energy efficient than commercially available ICs with similar frequency and range. The Bumblebee is targeted at body-worn devices in home health monitoring or rehabilitation settings. It has also received interest from chemical processing, sports fitness, and aviation companies with needs in miniaturized low power wireless sensors.



Assistant Professor Brian Otis with the Bumblebee.

The Bumblebee technology is already being deployed in various test settings. C4C's Mike Clarke has led the IP strategy and C4C has filed provisional patent applications. In addition, C4C has funded prototype development and demonstrations allowing real-world deployments of Bumblebee chips.

"C4C has connected us with relevant industries, and they are finding applications for our current technology while helping define our research goals moving forward," says Otis.

Staff in C4C's New Ventures unit and EIR Ken Myer have been working with the team to explore business models, partnering options, and how and when to pursue additional funding. Beyond biomedical applications, Myer sees even wider potential for next-generation Bumblebee sensors.

"We are just at the beginning of the next big technology wave—a revolution in wireless sensor networks. As the technology becomes cheaper, sensors will be embedded everywhere and we can't even begin to imagine all the applications," Myer said.

## Physware—the Formation of a Semiconductor Software Company

Professor Vikram Jandhyala and students at his Applied Computational Engineering (ACE) Lab in UW EE developed algorithms and software that can predict the electrical and electromagnetic behavior of complex electronics systems with unprecedented speed, scale, and accuracy—the foundation for start-up company Physware. This work, conducted from 2001 to 2006, received funding from DARPA, NSF, NASA, and industry collaborations, and led to many publications and recognition through research awards.

Led by C4C's Fred Holt and Patrick Shelby, C4C provided resources at every step in creating Physware—from protecting IP, to focused funding through a CGF grant and RRF, to helping secure start-up funding from Madrona Venture Group and Washington Research Foundation Capital. Upon Physware's founding in June 2006, Jandhyala took a two-year leave from the UW faculty to serve as the company's CTO and then CEO. Initial successes with high-profile customers enabled the start-up to attract senior business and technical leaders from the electronic design community. Jandhyala recently returned to the UW but continues to serve Physware as chief technologist and chairman of the board. Major customers include Texas Instruments, Toshiba, Panasonic, Tabula, and Vitesse.

"C4C was instrumental in helping me and my students take a complex array of ACE Lab innovations and build these into the foundation for a successful venture-funded start-up," Jandhyala said. "Our software helps electronics companies design products cheaply and get them to market quickly."



The Physware core team, with Professor Vikram Jandhyala (3rd from left), UW EE ACE Lab alumni Dr. Dipanjan Gope (far left), Devan Williams (2nd from left), Dr. Xiren Wang (5th from left), Dr. James Pingenot (4th from right), and Dr. Swagato Chakraborty (5th from right). Dr. Junho Cha, far right, is also a UW EE alumnus.

Jandhyala adds, "I am also excited that my involvement in every stage of the technology and company development generated knowledge beneficial to other UW EE faculty and students."

"I believe I have a repeatable model that can help others build deep computational IP into high-tech software companies. In my own lab, we are enhancing scalable algorithms to focus on important problems in cloud computing, large-scale internet computation, and social network applications that could lead to future licensable IP and start-ups."

**"C4C was instrumental in helping me and my students take a complex array of ACE Lab innovations and build these into the foundation for a successful venture-funded start-up."** — Vikram Jandhyala

## Getting started with C4C

Ready to share your innovation? Or interested in learning more about how C4C can help you on the path to commercialization? Talk to C4C at 206.543.0905 or email [uwc4c@uw.edu](mailto:uwc4c@uw.edu).

## C4C Organization & Roles

Over the past two years, C4C has enhanced its services at every stage of commercialization to better support UW researchers. C4C technology managers devote their full energies to researcher relationships, support, and outreach. Their work is complemented by talented specialists, including patent agents, veteran venture capitalists, entrepreneurs-in-residence, industry relations officers, and an SBIR grant writer. C4C is organized as follows:

### ■ Technology Licensing

C4C is organized with ease-of-use for researchers in mind. Each researcher is assigned to an individual Technology Manager with knowledge of their discipline area. The Technology Manager is a researcher's advocate from the first steps of exploration through the entire journey to market, funneling technology-specific resources to a project. As the primary link into C4C, the Technology Manager introduces the researcher to other specialists at C4C and C4C programs providing commercial funding such as the Commercialization Gap Fund (CGF) and commercialization post-doctoral fellows.

### ■ IP Management

The IP Management team is staffed to support multiple forms of IP assets, including patents, confidentiality and non-disclosure agreements, copyrights, trademarks, service marks, and certification marks. C4C's in-house patent agents can conduct a comprehensive search for patents and patent applications in a researcher's technical discipline, or file a provisional patent for a researcher who is presenting patentable research at an upcoming symposium.

### ■ Industry Relations

The C4C Industry Relations team identifies and introduces potential industry partners to UW researchers. C4C Industry Relations Officers work with department chairs and, in many cases, interdisciplinary research teams to design and administer corporate affiliate programs (CAPS). CAP membership can provide revenue for research and lead to sponsored research.

### ■ New Ventures

The C4C New Ventures program provides a suite of services, including consultation with experienced entrepreneurs and advisors, to spin-out UW start-ups. New Ventures services are intended to:

1. increase the value of UW start-ups by finding quality leadership, investors, and financing
2. address risks associated with:
  - technology prototype/proof of concept
  - intellectual property
  - management and/or team
  - market evaluation
  - regulatory and clinical strategy
  - ability to garner financing



**Mike Clarke**

**Engineering Technology Manager  
for C4C**

Mike Clarke joined C4C in February 2010 to focus on engineering innovations, especially in the electrical, mechanical, computer science, and materials science fields. His portfolio of technologies includes sensors, wireless devices, smart grid, nanophotonics, and self-assembly. Mike brings experience as a design engineer, project manager, and producer in multiple startup companies, in medium and large firms, and as an independent consultant. Mike earned a BS in mechanical engineering, an MS in smart product design from Stanford University, and a certificate in IP management from UW Extension.

# Students' Water-Testing Tool Wins \$40,000, Launches Nonprofit



Students Chin Jung Cheng, Howard Chizeck (Faculty Advisor), Jacqueline Linnes, Penny Huang and Charlie Matlack designed a way to know when water left in a plastic water bottle in the sun is safe to drink.

Winning the contest means the students' efforts may improve the health of children around the world. The challenge called for designs costing less than \$10. The UW students estimate their parts would retail for \$3.40, and bulk buying could reduce the cost further.

University of Washington engineering students Chin Jung Cheng, Charlie Matlack, Penny Huang and Jacqueline Linnes have won an international contest for their design to monitor water disinfection using the sun's rays. The students shared in a \$40,000 prize from the Rockefeller Foundation. A nonprofit organization is being established to turn their design concept into reality.

Solar disinfection of water in plastic bottles, also called SODIS is actually an old concept, and it has been promoted by many nonprofits. The competition was hosted by InnoCentive Inc., a Boston-based company that since 2001 has provided a website where organizations can post technical challenges with prize money and anybody can submit a solution. In this case, even the challenges themselves were solicited on the web. GlobalGiving Foundation Inc., a Washington, D.C. nonprofit that acts as a clearinghouse for charitable donations, asked nonprofits around the world to submit technical challenges relating to water quality. It then chose five to post to InnoCentive, and the Rockefeller Foundation supplied prize money. The competition to design such an indicator was for Fundación SODIS, a Bolivia-based nonprofit dedicated to testing and promoting this method. The Sodis Foundation evaluated more than 70 proposals before choosing the UW's.

Solar disinfection in water bottles offers a cheap and easy way to reduce some of the roughly 1.5 million diarrhea-related children's deaths each year because it removes more than 99.9 percent of bacteria and viruses, with results similar to chlorination. But global adoption has been slow, partly because it is hard to know when the water is safe to drink. The UW device lets users know when the sun's rays have done their job.

Jacqueline Linnes began working on the problem, motivated by her experiences in Bolivia with Engineers Without Borders (EWB). Other EWB members Penny Huang, a senior in chemical engineering, and Chin Jung Cheng, then an undergraduate in chemical engineering (now a UW doctoral student in bioengineering) joined her in the project. At first, the students focused on developing a chemical test strip. But they decided instead to develop an electronic sensor

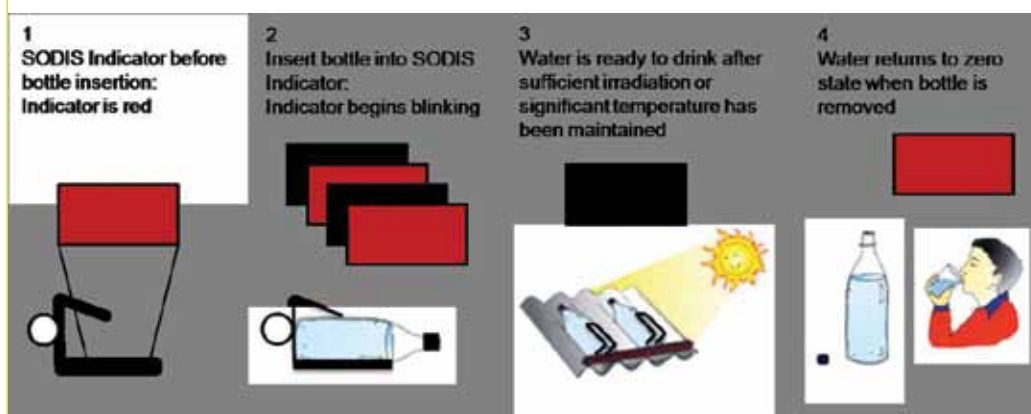
that would be outside of the bottle, which wouldn't require users to open the bottles. For this effort, they contacted Charlie Matlack, a UW doctoral student in electrical engineering.

Together they built a low cost, reusable and electronic system that is able to detect when the bottle has been exposed to sufficient light to provide the required sterilization of the water inside. "It has all the same components that you'd find inside a dirt-cheap solar calculator, except programmed differently," Matlack said. The electronics monitor how much light is passing through the bottle and whether a water-filled bottle is present, so the system knows when to stop or start recording data.

Winning the contest means the students' efforts may improve the health of children around the world. The challenge called for designs costing less than \$10. The UW students estimate their parts would retail for \$3.40, and bulk buying could reduce the cost further. "This is part of what engineering education should be," said faculty advisor Howard Chizeck, an electrical engineering professor. "It's educating students with the skills and the desire to make things better."

The Sodis Foundation has been given a nonexclusive license to develop the technology. It is also focusing on larger-scale systems that could be used in situations such as disaster relief. A Sodis Foundation donor is providing Charlie Matlack with funding to continue developing and refining the water bottle indicator.

Linnes, Matlack and Tyler Davis, a doctoral student in the UW Evans School of Public Affairs, are setting up a nonprofit organization to manufacture and market the device (<http://www.potavida.org>). They have recruited UW faculty and local nonprofits as partners (and potential partners), to draw on a broad range of expertise for the development of this solution to an important health need. "We're at a point where we recognize the need for work on this beyond engineering," Matlack said. "Ultimately, the hardest part is going to be to get people to use it."



An example SODIS indicator function.

# Physware: From University Research to Building & Leading a Successful Venture-Funded High-Tech Startup

## Professor Vikram Jandhyala

Director, Applied Computational Engineering Lab; UW C4C Inaugural Entrepreneurial Faculty Fellow; Chair, UW EE Professional Masters Program; Chairman and Chief Technologist, Physware Inc.



Vikram Jandhyala developed fast computational algorithms for electromagnetics during his PhD at the University of Illinois, for which he received graduate research awards from IEEE and UIUC. Subsequently, he developed algorithms and products for Ansoft Corporation, which was sold to Ansys Corporation for \$850 million. This showed Jandhyala first-hand the industrial benefits of efficient computational algorithms

for electronic design automation (EDA). At UW EE, Jandhyala and his Applied Computational Lab developed a host of paradigm-shifting novel computational algorithms and implementations which were of interest to several companies. This led to research funding from NSF, DARPA, NASA, SBIR and industry, and recognition through awards from NASA, UW and NSF. With his students and a top-class business team, Jandhyala led the formation of Physware, a venture-funded startup that now counts among its customers top semiconductor companies including Texas Instruments, Toshiba, Panasonic, Renesas, Micron, etc. Physware is at the forefront of cloud-based scalable EDA for high-speed, low-cost electronic system and design. Here, Jandhyala describes the research and IP development process, the formation of Physware, the industrial development/academic research interface, and the lessons learned for the future.

After joining UW EE in 2000, Jandhyala recruited top-class graduate students, and obtained sufficient funding through NSF, DARPA and NASA where he led projects as PI and Co-PI. In the first five years of these projects, he developed detailed implementations and prototypes of new fast algorithms for use in CEM, which were described in more than a 100 journal and conference papers. Additional grants from SBIR and industry, as well as focused projects from UW's TGIF and RRF, and gifts from WRF subsequently followed. Specifically, Jandhyala's team was able to develop scalable, structured dense matrix solvers which could solve large systems in only  $O(N \log N)$  time and memory in a robust and error-controllable manner. They made these algorithms as parallel as possible from the ground up, which now has new implications in the world of public cloud computing.

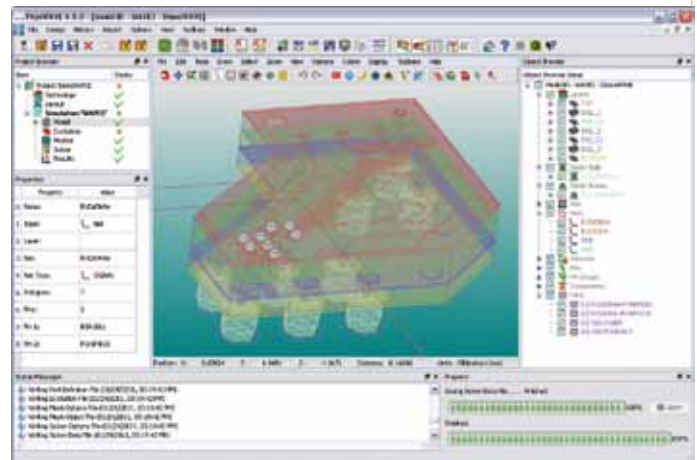
In late 2006, Dr. Luciana Simoncini from the Washington Research Foundation visited UW EE and asked former chair, Dr. David Allstot, for examples of interesting technologies. Allstot mentioned Jandhyala's name, and through his meeting with Simoncini, he was able to connect with UW Technology Transfer (UWTT, now C4C) and, in particular, with Dr. Fred Holt who played an invaluable role in the formation of Physware. Dr. Holt helped develop an IP strategy to protect the algorithm implementations through patents and copyrighting, and also assisted with introductions to the local venture capital community. As a result, two large EDA companies were interested in licensing the algorithms and software.

With help from UWTT, Jandhyala started to navigate the path towards forming a startup. Along the way, Jandhyala was able to call on experienced faculty including Dean Matt O'Donnell, former Associate Dean Mani Soma, and former CS Chair Dr. Ed Lazowska for guidance. Dr. Holt helped set up multiple meetings with local VCs, and they raised funding (after following points 1-5 in the recommended keys in the inset) from Madrona Venture Group and Washington Research Foundation Capital, with additional seed funding.

The process accelerated and they recruited an accomplished business person and also recruited an excellent technical team based on ACE Lab alumni including two of the initial developers of the core IP, Dr. Dipanjan Gope and Dr. Swagato Chakraborty, as well as Dr. James Pingenot, Devan Williams, and later Dr. Xiren Wang. This team handled all technical expertise, from fast algorithms, full solver implementations, parallelization strategies, front-end and mesh development, and user interface design.

## Keys to Developing a Startup from University Research

1. Develop and protect deep IP
2. Critically evaluate the true benefits of your IP
3. Obtain early adoption and industrial feedback
4. Be aware of the bigger industry picture
5. Build a short slide deck to crystallize business ideas
6. Raise money for the right reasons
7. Build the right core and extended team
8. Understand and evaluate competition realistically
9. Adapt when situations change
10. Share the experience with others



A snapshot from the Physware product. These software tools use advanced electromagnetic-circuit computational algorithms to simulate and design complex electronic systems.

Jandhyala took leave from UW EE to play the roles of CTO and CEO at various times, spent significant time at customer sites (including ten visits to Japan in little over a year), and worked to understand negotiations between UWTT and Physware in terms of licensing agreements, potential conflicts of interest, and creating a firewall between the ACE lab and Physware. It was an extremely fruitful experience for Jandhyala and for Physware as well as for Jandhyala's former students.

At the time of returning full-time to UW EE in fall 2010, Physware has built a cache of customers that include many of the top semiconductor companies around the world, and has recently stepped to another level. Physware has attracted top-class business and technical leadership from Synopsys (a \$1B+ company and the world's largest and most respected EDA company), raised further venture funding, is building up many existing customers to enterprise level, and is now using the power of its parallel algorithms to make a stake as the world's first cloud-computing based EDA provider, a potentially paradigm-shifting move on both business and technical fronts. Jandhyala has completed the process of building and leading his startup through its first successful phase, and has now returned to academia to work on new research and follow-up applications at the ACE lab. This includes information theory for electromagnetics, parallel and cloud computing algorithms, fast solvers for computational finance, network and RFID applications, recommendation engines and matrix completion, and diffusion and search graph applications.

Jandhyala believes that those who are interested in entrepreneurship can play a meaningful role in both academia and industry by leading innovative research, and developing startups that solve society's most urgent issues, especially given today's crucial economic times. UW EE is well equipped to have several startups emerge along these lines if the correct and sometimes difficult choices

are made to focus on technically deep and long-term challenges that academia has excelled at. UW EE is then well situated to maintain and build respect as a top department that generates world-class ideas, papers, graduates and companies.

The lessons learned from developing Physware are something that Jandhyala believes would be invaluable for graduates and undergraduates interested in pursuing entrepreneurship. He is currently developing an "Entrepreneurship for EE's" seminar course for 2011-12. Jandhyala believes that meaningful entrepreneurship is a strong "fourth wheel" for the faculty vehicle, along with the research-teaching-service triumvirate. UW EE can be a leader in this direction given the quality and zeal of the faculty and students.

## Jandhyala named an Inaugural Entrepreneurial Faculty Fellow by C4C

Professor Vikram Jandhyala was selected in November 2010 by the UW Center for Commercialization to be an inaugural Entrepreneurial Faculty Fellow. Candidates for this honor were nominated by department chairs and C4C technology managers. Jandhyala will work with the UW, venture, and angel communities to provide leadership and advising on commercialization and entrepreneurship related to UW technologies. For more information, visit: [www.ee.washington.edu/news/2010/entrepreneurial\\_fellow.html](http://www.ee.washington.edu/news/2010/entrepreneurial_fellow.html)

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Congratulations to Vikram  
 Jandhyala and Radha Poovendran  
 who were promoted to full  
 Professors.

We apologize for any errors,  
 omissions or misspellings in 2011  
 EEK. We would like to extend  
 special appreciation to the faculty,  
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# New Faculty

## EE Students Hack Kinect for Surgical Robotics Research



### Kai-Mei Fu

Kai-Mei Fu received her Ph.D. from Stanford University in 2007, and will join as an Assistant Professor of Electrical Engineering and Physics in Fall 2011. Her research focuses on solid state spin systems coupled with optical fields for applications in quantum information processing and magnetic sensing. Particular material systems of interest include shallow impurities in semiconductors, color centers in diamond, and semiconductor quantum dots.



### Daniel Kirschen

Daniel Kirschen joins the department as a Full Professor and holds the Donald W. and Ruth Mary Close Endowed Professorship in Electrical Engineering. His research focuses on how to balance the conflicting requirements for the supply of electrical energy, and in particular how to keep it cheap, reliable and facilitate the integration of renewable energy sources such as wind power. This encompasses the implementation of the communication and control technologies of what is called the "smart grid." He is also very interested in understanding the mechanisms leading to blackouts and what can be done to prevent such catastrophes. Kirschen received his Ph.D. from University of Wisconsin-Madison in 1985.



### Joshua Smith

Joshua Smith joined the departments of Electrical Engineering and Computer Science and Engineering as an Associate Professor in Winter 2011. Smith obtained his Ph.D. from MIT in 1995. As a doctoral candidate at the Massachusetts Institute of Technology, Smith invented an electric-field-based passenger airbag suppression system that is now standard equipment in all Honda cars. Smith currently leads projects on Personal Robotics, WREL (Wireless Resonant Energy Link), and WISP (Wireless Identification and Sensing Platform).

Researchers and hobbyists have hacked the Kinect gaming system since its November launch to explore uses beyond video gaming. It is possible to tap into the Kinect to obtain a depth camera image of a scene—representing a dynamically changing image as a constantly changing "point cloud" of dots that include information about distance of objects from the camera. This provides an extraordinarily low cost way to collect such information.

Research at the Biorobotics Lab (BRL) is exploring ways to provide haptic (sense of touch) feedback to surgeons using robotic tools. This surgery is performed by remotely controlling robot surgery tools, which pass through small holes into the patient. In currently used systems, the surgeon commands the device using hand controls, while looking at a video display from camera images in the body. There is no sense of touch for the surgeon. Professors Blake Hannaford, Howard Chizeck, colleagues from the UW medical school and their students are working to change this. "In telerobotic surgery, surgeons are basically unable to feel what they're suturing or cutting," Chizeck said. "We'd like to get that sense of feeling back."

This work in telerobotic surgery aims to make it possible for surgeons to operate at a distance on patients in disaster areas, on battlefields or in other inaccessible places. Use of the technology contained in Kinect can help meet this goal. It would be useful to provide surgeons with haptic feedback about "don't cut" zones around protected areas of tissue. When trying to cut there with a robotic tool, the surgeon would feel resistance. But how can these zones be specified.

One difficult way would be to use pre-operative CT scans. But this is not easy to do, and can't account for position changes as the patient breathes or moves. The Kinect, which can track the movement of objects, provides a tantalizing solution. "As soon as we saw the Kinect, it seemed like, yeah, let's play around with it. It just seemed obvious and cool," said Hawkeye King, a doctoral student of the BRL. "We work in haptics, building virtual environments that touch remote locations. This is an interesting way for building virtual worlds from real worlds, and even combining the two."

Among the so-called hackers is Fredrik Rydén, a visiting graduate student from Sweden working with Chizeck and Hannaford. During a weekend in December, Rydén reprogrammed a Kinect to add sensory feedback. "I bought the Kinect on a Friday and was done on Monday morning," Rydén said.

## Going Viral — A Timeline



Rydén and King recorded a video of the modified tool and posted it on YouTube. In the video, the Kinect's infrared camera points at a table where Rydén is seated. The upper right-hand corner shows King operating a stylus that gives force feedback, in the form of a push, when he meets an object in the virtual scene. The red dot shows where the stylus is positioned.

When the red dot moves over an object the stylus feels the resistance, a field known as haptics. The video shows that King can not only tap solid objects, like the table, but can also feel a new object (in this case a Styrofoam head placed on the table) and even shake Rydén's hand in real time.

"The virtual world is generated in real time from the real world," Rydén explained. "In this case he was in the same room, but he could have been anywhere and seeing the information on the Internet." Another bonus, he said: "Kinect is cheap because it comes from video games and it's mass produced."

The UW team is exploring the Kinect's potential to improve surgical robotics by creating "virtual fixtures" around body parts that should not be touched. The Kinect's simple interface, low cost and portability make it well suited for doing feasibility experiments. "We could have had students spend several quarters to do what one student has done in less than one quarter using the Kinect," Chizeck said. "This is just a very efficient way to track moving objects. It's unlikely that any final device is going to have the Kinect in there," Chizeck added, "but it's a way to test ideas quickly and develop them."

A video demonstrating the haptics-Kinect work conducted at UW EE's BRL has gone viral, grabbing the attention of the media. Here is a brief timeline showing just how quickly public interest in the research of the BRL spread:

- 12.16.2010** Students post YouTube video demonstrating BRL's haptics-Kinect work: [http://www.youtube.com/watch?v=bcUCDns\\_7Qc](http://www.youtube.com/watch?v=bcUCDns_7Qc)
- 12.31.2010 - 1.5.2011** Local news cover BRL's work on radio and tv channels (KOMO 4 News, KIRO 7 Radio, UW Today)
- 1.7.2011** Chief Research and Strategy Officer of Microsoft, Craig Mundie, speaks about the evolution of computing during a presentation at the Cleveland Clinic, which included a discussion about the haptics-Kinect work at BRL
- 1.18.2011** Popular Science picks up the story
- 1.25.2011** Bloomberg Businessweek: GigaOM blog discusses the BRL's research with respects to the "Power of Big Broadband"
- 1.31.2011** YouTube video receives 27,000 hits
- 2.15.2011** MSNBC posts a video and article on BRL research

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This "Kirit Hope Wooden Jigsaw Puzzle" is an example of some of the creative entrepreneurial activities of UW EE faculty and students. Puzzle from Associate Professor Maya Gupta's company, *Artifact Puzzles*. Photo by EE graduate student, Leo Lam.

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