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THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

BIOLOGICALLY INSPIRED ENGINEERING

Application of Natural Systems to Engineering at NASA

Auto-Gopher 2—A Biologically Inspired Deep Drill for Planetary Exploration

Leveraging Nature's Gifts in the Design of Control Systems

Design of a Bio-inspired Optical Current Transducer

Dinosaurs Make Light Work—From the Engineering Problem to an Innovative Lightweight product

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THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

2016–Biologically Inspired Engineering

FEATURES

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Our Cover
See page 7 for details on cover images

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Greetings,

Welcome to the inaugural issue of THE BRIDGE for 2016! It is hard to believe I am writing this column with about a week to go in 2015. Time flies when you are having fun!

And IEEE-HKN continues to inspire each and every one of us to uphold the highest ideals of our honor society, and more importantly continue to do everything we can to serve our profession and society. If you wanted an example of the breadth and depth of our society's impact all you had to do was to be at the annual IEEE Educational Activities Board Awards banquet in November to see and hear about the wonderful accomplishments of our honorees. From Payman Deghanian whose research on reliability-centered maintenance has helped improve cost effectiveness in the electric power industry, to Preethika Kumar whose teaching and stimulating classroom environments that inspire future engineers, and Asad Madni whose contributions to MEMS gyrochip technology which is ubiquitous in Electronic Stability Control and Rollover Protection systems in passenger vehicles today, it is clear that IEEE-HKN is making an incredible difference in our lives and careers.

As I observed in my previous column, the IEEE-HKN Board of Governors along with our professional staff colleagues is deeply committed to ensuring the continued success of IEEE-HKN in the year ahead. In this context it is fortuitous that I have the opportunity to serve IEEE in a dual role next year as Vice President, Educational Activities. You can count on me to do everything I can to strengthen IEEE-HKN and ensure its full integration into IEEE with the support of the Board. Our top priority is to build a strong and sustainable financial foundation to support IEEE-HKN into the future. The ad-hoc Public Relations and Communications Committee has done a tremendous job this year with its work on all aspects of Public Relations, Visibility & Communications of IEEE-HKN, ranging from Social Media, to our signature publication THE BRIDGE, and the upcoming launch of Virtual Campus. Looking ahead it is important that this committee become a standing committee of IEEE-HKN to ensure continuity and sustainability. These efforts will strengthen our membership and connect meaningfully with IEEE-HKN alumni all over the world. On the corporate front we will be moving ahead purposefully this year to engage industry partners in IEEE's myriad fields of interest to invest in IEEE-HKN.

Plans for our 2016 annual student leadership conference at the University of Michigan, Ann Arbor are shaping up nicely and I hope to see many of you there. Meanwhile if you wanted an example of the creativity and collaboration that is intrinsic to engineering check out UM Dean Dave Munson's tribute to Star Wars in this fun and engaging video at https://www.youtube.com/watch?v=UgNmfada2TQ#t=64

Who said Engineers don't have fun? ☺ May the Force be with all of us for a fabulous year ahead! And as always please don't hesitate to let us know if you have any suggestions or comments to improve our organization and build a stronger IEEE-HKN.

2016 IEEE-HKN President

Dr. Steve E. Watkins

Gamma Theta Chapter

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Dear Eta Kappa Nu Members and Friends,

THE BRIDGE magazine continues to improve to better serve our members and the organization. I hope that you enjoy our format redesign. I appreciate the work of the editorial board, the IEEE-HKN staff, and our new publishing partners at Allen Press.

I applaud the efforts of our guest editor Dr. Jacquelyn Nagel to address the broad theme of "Biologically Inspired Engineering." The solution of engineering problems by considering biological sciences and the workings of nature can be a rich approach to design. The features highlight the interdisciplinary aspects of such design and the varied innovations that are possible. The mimicry of biological systems has produced many useful technologies over the years, but current efforts at biologically inspired engineering seek to develop and to model processes of design that methodically identify connections between biology and engineering domains.

The history content in our last issue prompted memories of my start in HKN. I share my inductee plaque from 1982. The Gamma Theta Chapter still maintains the pledging tradition of finishing a blank bridge and obtaining signatures of current members and faculty. Asking for a signature was my introduction to many faculty and upper-class students. What a great way to make a first impression! As my chapter's advisor, I enjoy getting to know our inductees through the plaque signing process. I hope that your chapter has equally memorable traditions.

I welcome your comments and suggestions.

Regards,

1982 Inductee Plaque for the Gamma Theta Chapter

Nancy M. Ostin

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Our 2016 opportunities and challenges …

Our focus will continue to be:

Support our chapters, volunteers, and members to expand IEEE-HKN both in number of chapters and members as well as the impact and value delivered by our chapters and program.

Automate administrative functions to improve the member and volunteer experience and integrate fully with the systems of IEEE.

Develop new and expand the funding/revenue sources of IEEE-HKN to support our growing program.

To achieve these goals we will need all of you – our current students and faculty, our alumni, volunteers and IEEE MGA and Technical Activities volunteers, to integrate with IEEE and deliver on the promises of the merger and the value proposition of IEEE-HKN to all of IEEE.

As the Staff Director of IEEE-HKN I look forward to working with you and your groups to our mutual benefit and to create a stronger IEEE through IEEE-HKN.

Comments? Questions? Suggestions? To volunteer or to inquire about all things IEEE-HKN, please contact me directly, I look forward to working with you.

Sincerely,

Director, IEEE-HKN

Dr. Jacquelyn K. Nagel

Gamma Theta Chapter

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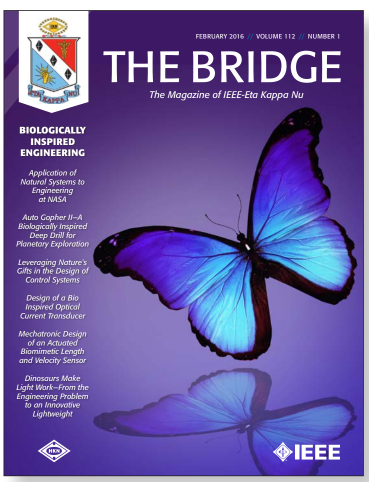
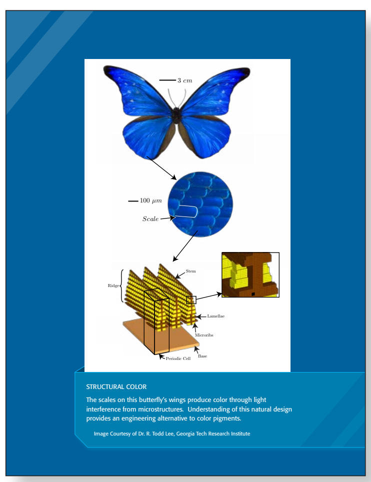
Dear Readers,

Are you curious how engineers can create innovations by taking inspiration from nature? You will be pleased to find a range of innovations inspired by nature, from conceptual to commercial, in this special issue with representation of multiple engineering disciplines as well as biological inspiration.

Biomimicry is a design philosophy that encourages us to learn from nature, and results in discovery of non-conventional solutions to problems that are often more efficient, economic, and elegant. The front and back cover images are excellent examples of learning from nature. Researchers learned that butterflies create their vibrant colors not from pigments and dyes but from specialized microstructures on the surface of the butterfly wing. Butterflies have taught us how to use form to produce color, which is now known as structural color.

My vision for this special issue was to educate readers about the field of biomimicry in a variety of contexts. The feature articles in this special issue showcase the breadth of this design philosophy with inspiration from biological function (what the system does), form (geometry, shape of system), behavior (system response to stimuli), and strategy (generic behavior exhibited among multiple biological ranks to achieve different goals). The reader will also discover there are multiple approaches to biologically inspired engineering each with their own advantages and disadvantages. Additionally, there are articles from both industry and academia, which I believed to be a critical requirement for the special issue. I wanted to inform readers that biomimicry is not just a fad, but has made (and can make) valuable contributions to engineering.





I hope you enjoy the special issue!

Best,

About our cover

Our front and back covers feature the beautiful colors of a blue morpho butterfly, with further detail of the butterfly wing structure highlighted on the back cover.

BACK COVER CREDIT: Courtesy of Dr. R. Todd Lee, Georgia Tech Research Institute

IMAGE SOURCE: Detailed electromagnetic simulation for the structural color of butterfly wings. R. Todd Lee and Glenn S. Smith, *Applied Optics* Vol 48, Issue 21, pp. 4177-4190 (2009) doi: 10.1364/AO.48.004177

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Application of Natural Systems to Engineering at NASA

Kennie H. Jones, George M. Studor, and Jacquelyn K. Nagel[1]

Abstract

Nature has provided inspiration for aeronautical and space travel long before the National Aeronautics and Space Administration (NASA) was created. Now NASA is finding renewed interest in using the knowledge and mimicry of nature to build technology and vehicles and accomplish new missions. The goal of this work is not to cover the entire spectrum of natural systems and all ways it can be applied to engineering and technology. Instead, some of the past, present and future NASA challenges will be presented that were or could be solved by applying concepts learned from natural systems and some specific applications will be discussed that demonstrate a paradigm shift at NASA placing increased value on the knowledge of the natural world. The relationship of the emerging world of autonomy and the philosophy of antifragile design with natural systems will be described as well. These changes result in not just more elegant solutions, but a bolder vision and process change that includes natural systems facilitating improvements not possible with incremental improvements to man-made systems and demonstrate that the time is now for NASA and others engineering organizations to adapt to take advantage of the challenges and opportunities afforded by natural systems.

I. Introduction

Nature has provided inspiration for aeronautical and space travel long before the National Aeronautics and Space Administration (NASA) was created. In its past, NASA has applied natural systems concepts to solve engineering problems but now NASA is finding renewed interest in using the knowledge and mimicry of Nature to inspire future directions, respond to challenges, build technology and vehicles, and accomplish daring missions. Spurred on by success stories and emerging technologies, investments are now being made to make considering nature more systemic in the way engineers and technologists think about addressing challenges and solving problems.

Before there was a NASA or the Wright Brothers, there was the desire to fly and understand the heavens. And before that, there was the study of nature itself: man studied fire from nature to make his own fire; he studied nature to predict future events; he studied living things to relate, control or mimic them, if it was useful. Understanding how to use or copy nature is and has been a key factor of man's survival. As we become more capable of understanding and copying what nature does, it only makes sense to put in place methods for doing it more effectively – not just stumbling on a discovery from nature, but making both the question and discovery a part of the standard engineering process.

NASA's vision is to broaden and deepen opportunities, change mindset, and change relationships and processes in engineering and technology by linking

[1] Kennie H. Jones, Ph. D., is an employee of NASA located at the Langley Research Center, Hampton, VA (e-mail: k.h.jones@nasa.gov). George Studor is a retired NASA engineer and is now a consultant for the NASA Engineering and Safety Center (e-mail: gmstudor@gmail.com).
Jacquelyn K. Nagel, Ph.D., is an assistant professor in the Department of Engineering at James Madison University in Harrisonburg, VA (e-mail: nageljk@jmu.edu).

them more closely with the science and replication of the living and non-living natural world. Inventions using biomimicry only sometimes find their way to successful applications but, if engineering and technology will look for solutions from nature, there will be a greater demand for the existing biomimicry and the research that leads to other nature-based solutions.

NASA must not only overcome the known challenges of Aeronautical, Earth, and Space Science and Space travel, but also to formulate the new challenges that drive invention and innovation. The innovations possible by looking to nature have often allowed for amazing leaps forward compared with incremental improvements to performance of previously working systems. Individual success stories of application of biomimicry will continue to increase within NASA, but the real breakthrough will come when NASA chooses as an organization to systematically incorporate natural systems inspiration into its way of thinking and in its engineering and technology design processes. NASA engineering and technology should become a much stronger customer for natural science research and development. Since the vast body of natural systems knowledge and mimicry resides external to NASA, it will be extremely important for NASA to develop better connections to the rest of the world. Then it can work on application and integration of what has been done and identify, stimulate and fund the important areas that have not.

NASA has a number of diverse missions that could greatly benefit from the application of natural systems concepts to engineering solutions. Natural systems could provide inspiration for solutions to efficiency, safety and mission assurance, inspection, crew factors, sensing, mapping, sampling, docking and capturing, characterizing and exploring, and construction for such diverse missions as The International Space Station, missions to Low Earth Orbit (LEO), long duration robotic and manned missions (each with unique needs at the destination), manned habitats, and planetary surface/resource exploration. Natural systems could provide inspiration for efficiency, safety, performance, cooperative/formation operations, and new capabilities for autonomous and efficient aircraft operations, airspace cooperation, and UAV operations. For Earth Science, natural systems could provide inspiration for solutions to efficiency, safety and mission assurance, sensing, mapping, sampling, and exploring in satellite, balloon, piloted aircraft and UAV applications.

In the following sections, some past and present successes are presented and opportunities for future success are identified. Section II describes specific applications of natural systems concepts to engineering challenges of machine mobility. In Section III, a relationship is described between the rapidly developing and very important strategic direction in aerospace, *autonomous systems*, and the opportunity for significant progress through the application of natural systems concepts. Section IV describes specific applications of natural systems concepts to engineering challenges of autonomy. Section V defines the philosophy of *antifragile design*, describes the relationship between it and natural systems, and argues that natural systems may provide inspiration to realize antifragile systems. Section VI describes specific applications of natural systems concepts to engineering challenges of antifragility. In section VII, some efforts at NASA are described to formalize and change engineering to include natural systems concepts as inspiration in the system engineering process.

II. Applications of Bio- inspired Design to Mobility

Natural systems have been used for inspiration since the beginning of aeronautics. Honeycomb-based structure for aircraft was patented by Hugo Junkers in 1915 [1]. Velcro, though not invented by NASA but originally inspired from thistles, has been used in space for temporary adhesion since the Apollo program. With the increasing use of robotics, natural systems have served as inspiration for improving methods of mobility and, in the following subsections, several examples of how NASA has used this inspiration to research and develop systems for machine mobility are given.

A. Morphing Wings

The shape of conventional wings on aircraft is fixed with small variability in foil shape through ailerons (increasing curvature increases lift at cost in drag). Aircraft design is a tradeoff between stability (needed for safety) and instability (needed for agility). The more stable the aircraft, the safer, but the less agile, it is. Fighter and acrobatic aircraft are less stable but more maneuverable than passenger liners. But, the stability of aircraft is fixed at design, except for small variability of control surfaces. Possible now by improvements in multi-functional, smart materials and structures, a morphing wing [2], operating more like a bird's wing, can improve ability to vary the characteristics of the wing in flight, providing greater flexibility and adaptability of shape, thus opting for increased stability or agility as needed. NASA is proving that drag and weight can be reduced by "seamless" (no hinge) control surfaces, and advanced controls to sense and command the optimum shapes to produce the desired flight vehicle response. NASA explored morphing shapes and controls with Texas A&M in 2006-7 [3]. Then the Active Aeroelastic Wing (AAW) F/A-18 project [4] was able to demonstrate reduced coordinated tail surface input to obtain the same turning results as with standard F-18 rigid controls. Now in 2015, the Adaptive Compliant Trailing Edge (ACTE) project with AFRL and FlexSys, Inc. replaced standard flaps with morphing flaps on a Gulfstream III flying test bed in 2015 [5].

A morphing wing, with its greater flexibility of shape can assess conditions *in situ*, respond to those conditions within its increased limits of flexibility, and adjust its characteristics appropriately. This would not only lead to higher performance and efficiencies in flight but would also allow greater flexibility so that a single aircraft could easily be adapted for multiple missions. Benefits of this biomimetic approach to wing design for future military and commercial aircraft are important and practical. inspired

B. Bird-like Aircraft with No Vertical Tail

In typical aircraft, adverse yaw (a product of lift) has been overcome by a vertical tail and associated fuselage to provide controlled flight. Birds, however, have no vertical tail and they avoid the adverse yaw problem. NASA [6] has lead an effort to demonstrate work began by Prandtl, who, inspired by birds, figured out that a 22% increased span (think of a horizontal winglet) would provide negative adverse yaw, effectively "thrust" from the inboard vortices. The solution, demonstrated by the Prandtl flight tests at Armstrong Flight Research Center, maximizes performance, minimizes structure and provides coordinated flight–like a bird. NASA hopes to move from the complex "flying wing" aircraft of the past, like the YB49, the B2, and the solar-powered Helios to a much lighter and simpler implementation of the flying wing and its derivatives. This concept may also have application on propellers and for noise reduction.

C. Tumbleweed-like Planetary Surface Explorers

NASA needs efficient ways to explore planetary surfaces. In 1977, NASA Jet Propulsion Laboratory (JPL) originally conceived the idea of wind blown balls for the surface of Mars as a passive mode of transportation [7]. Instead of wheeled rovers, some engineers have been inspired by thistles and tumbleweeds to create ball-like exploration robots [8]. The concept is an autonomous rover that achieves mobility as it is propelled by Martian winds. It thus becomes a practical platform for conducting random surveys of the surface. NASA Langley Research Center (LaRC) studied the dynamics, aerodynamics, and mission concepts as early as 2003 and developed a prototype Mars Tumbleweed Rover for demonstrating mission concepts and science measurement techniques. In 2004, JPL demonstrated its tumbleweed inspired ball robot in the Antarctic [9].

D. The "Hedgehog" robot

A hedgehogs' defense mechanism is to roll up in a ball and point its sharp quills outward and will "pop" – hoping to ward off a threat. Funded by the NASA Innovative Advanced Concepts (NIAC) Program, researchers at JPL and Stanford developed a *Hedgehog* robot that is cube-shaped with spikes in its corners for traversing the very low gravity of an asteroid using gyroscopic momentum to roll, hop, and even spin. The bio-inspired robot prototypes were successfully tested on the NASA C-9 Reduced Gravity aircraft in June of 2015 [10].

E. Mobility Through Biotensegrity

A science called Biotensegrity [11] takes the "tensegrity" concept and applies it to biological functions, such as motion of the human spine or snakes. Biologically inspired tensegrity research is transforming the way some robotics is being implemented. For example, the "Super Ball-Bot," led by NASA Ames Research Center (ARC) [12], is an all-in-one, collapsible, landing and mobility platform, allowing for lower-cost, and more reliable planetary missions. Designed as a sphere-like matrix of cables and joints, the Super Ball Bot can withstand high impact planetary entry. Once on the planet, the joints can adjust to roll the bot in any direction while housing sensors and other infrastructure safely inside the outer joints.

III. The Relationship Between Autonomy and Natural Systems

Although automation has progressed throughout the industrial revolution, new developments are accelerating its use and utility worldwide. All future

NASA missions will be increasingly dependent on autonomous systems. The following subsections detail that dependence in NASA's three major mission areas and how natural systems provide inspiration for design and implementation of required autonomous systems.

A. Autonomy in Aeronautics

In early 2015 NASA's Aeronautics Research Mission Directorate (ARMD) released its latest Strategic Implementation Plan (SIP) [13] defining six Strategic Thrusts revealing its vision of aeronautical research for the next 25 years and beyond. The goal of that vision is to meet future needs for safe, efficient, flexible, and environmentally sustainable air transportation.

While the SIP does not define autonomy, it titles the sixth Strategic Thrust (ST6), *Assured Autonomy for Aviation Transformation*. ST6 describes a community vision where increasing autonomous systems will provide improvements in safety, efficiency, and flexibility of operations thus transforming aviation to increase the capacity, robustness, and flexibility of the National Air Space (NAS). Additional benefits will be realized through new vehicles enabled by advances in autonomy such as Unmanned Aircraft Systems (UAS) and on-demand personal air transportation.

The other five Strategic Thrusts are more mission directed in specific research areas guiding ARMD's response to global trends affecting aviation. However, it is clear in their detailed descriptions that improved technologies for autonomous systems are critical to achieving their goals and all are dependent on results of Strategic Thrust 6.

B. Autonomy in Space

Requirements for future space missions are calling for increasing and improving autonomy. Mars rovers are reaching the limits of their capabilities and new missions are impractically hampered by communication bandwidth and long latency required for remote human control. These limits are worse for deep space missions.

In 2004, President George Bush announced the Vision for Space Exploration [14] with the goal for NASA to develop new technologies for harnessing the moon's natural resources to more practically support manned space exploration. For the Apollo missions, everything required by man was brought from Earth, manufactured for the journey. By utilizing resources on the moon, Mars, or other destinations, to manufacture, *in situ*, required items, total launch mass could be substantially reduced. Though the concept of utilizing resources at the site of exploration, named In-Situ Resource Utilization (ISRU), had been proposed before the first Apollo landing on the Moon, it was deemed impossible at the time. In the decades since then, development of this capability had not progressed much but recently, new technology promises feasibility. In 2005, NASA created the ISRU Project in the Exploration Technology and Development Program (ETDP) [15]. The first goal of ISRU was to substantially reduce the expense of humans traveling to and from and operating on the Moon and Mars by utilizing resources at the site of exploration to create products and services locally. Additionally, ISRU increases performance of missions and enables new mission concepts by eliminating the requirement to bring all needed equipment as completely manufactured goods from Earth. A longer-term benefit is to create an environment locally that is self-sufficient for long-duration manned bases enabling increased and new exploration, and, eventually, enabling commercialization of space. ISRU is a massive increase in scale and capability of current exploration technologies and cannot be accomplished with human remote control of machines: substantial improvements in autonomy is required.

C. Autonomy in Earth Science

The study of the Earth has been expanded and improved through the use of remote sensing from satellites. However, the cost in funding and development time together with the substantial launch costs for the mass of these large satellites limits deployment. Recent improvements in standardization, miniaturization, materials, use of commercial off-the-shelf components, and other technologies have made possible a new concept, CubeSats. CubeSats may be launched with the intention of forming arrays or a collaboration of an independently orbiting swarm of satellites. Autonomous systems will increase the utility and decrease the cost of operation and maintenance of these networks.

In addition to satellites, sensors have been carried by high altitude balloons and piloted aircraft. Balloons have long endurance but limited targeting mobility. Piloted aircraft have precise mobility but limited endurance and range, mostly limited by pilot duty hours. Long endurance UAVs show promise of distinct advantages for this task [16]. They provide the mobility of piloted aircraft at lower cost and, more importantly, lower risk to human life. Without pilots, their endurance is increased with improving energy technologies furthering this advantage. Flying a remote piloted UAV requires some level of automation but to achieve full potential of long duration requires autonomy.

D. Why is Autonomy related to Natural Systems?

The English word autonomy is derived from the Greek roots, *auto* meaning "self" and *nomos* meaning "custom" or "law." Early use of the word was applied to people and reflected the political sense of the word: a group's right to self-government or self-rule. When a person or group seeks autonomy, they would like to be able to make decisions independently from an authority figure, with those decisions serving the goals of the individual or group; not of the prior authority. This is not the definition of autonomy applicable to the goals of the SIP. Theirs are more closely linked to Isaac Asimov's Three Laws of Robotics [17]:

1. A robot may not injure a human being or, through inaction, allow a human being to come to harm.
2. A robot must obey the orders given it by human beings except where such orders would conflict with the First Law.
3. A robot must protect its own existence as long as such protection does not conflict with the First or Second Laws.

Combining the three, an autonomous machine must do what humans want it to do without causing harm. Its autonomy is not an authority to make its own laws but a delegation of decision; a delegation of human decision. Is this not biomimicry? The autonomous machine is designed to mimic, to some level, human decision.

Such autonomy brought about the industrial revolution: machines were invented to offload manual labor such as the loom to weave cloth. The first autonomous machines were delegated to perform a prescribed action repeatedly without human supervision or interaction. The prescription of a watch is, in the precise design of its gears and springs such that, with periodic winding, it will autonomously and accurately update its display of time.

In time, machines were developed that could not only perform the duties of humans but could also perform these functions faster and better (e.g., more accuracy, more power, etc.). With purely mechanical decision gates, prescriptions grew in complication but were limited. With the introduction of computers came Cyber-Physical Systems (CPS), which opened the door for more complex control of machines and the potential for adaptive behavior. A CPS is a combination of perception systems that gather situational awareness of the environment (more than sensing), a decision-making component (e.g., the computer), and actuators. The first generation of CPS was relatively simple machines that monitor the environment and direct an actuation (e.g., controlling gas flow to an engine). The second generation of CPS presents a system of systems approach where ubiquitous and pervasive CPS are networked together and decisions are made by this network. Such an application becomes a complex system that is more than a sum of its parts: decisions come not from a reductionist design of the components but from their interaction.

The model for CPS, perception, decision, and action, can affect a wide range of capability. The simplest CPS has a prescripted directive determined at design that will effect an action when appropriate. Although it may monitor sensors to determine the required actions, all actions are predetermined. The full potential for CPS extends to pervasive perception with complete situational awareness and cognitive decision engines that store observations, learn from these observations over time, and use that learning to adapt their behavior in ways that could not possibly be predetermined at design. This is often expressed as a continuum from simple automation to full autonomy along which requires ever increasing autonomy. However, it is better described as an evolutionary tree, similar to biology, where developments, though useful at the time, will have an end of life as they are replaced by better systems.

Unfortunately, much discussion around autonomous systems is centered on the action component of the trilogy: what do we want the machine to *do*. But for most of the desires for the future, the perception and cognition components are paramount in how machines do what we want. In applying autonomy, engineers tend to concentrate on the action of the machine. However, it is the intelligence, provided by perception and cognition, which will direct the action and enable increasing abstract delegation. Tim Urban in "The AI Revolution: The Road to Superintelligence", warns of this important distinction [18]:

To understand artificial intelligence, "First, stop thinking of robots. A robot is a container for AI, sometimes mimicking the human form, sometimes not—but the AI itself is the computer inside the robot. AI is the brain, and the robot is its body—if it even has a body."

The intelligence we require for the desired autonomy is not simply a matter for more and better sensors connected to higher performance computing. Artificial Intelligence researcher Donald Knuth [19] presents the challenge:

"AI has by now succeeded in doing essentially everything that requires 'thinking' but has failed to do most of what people and animals do 'without thinking.'"

So, NASA's desires for autonomy in aeronautics, space, and science require a delegation of human observation, decision, and action to machines: a biomimicry of humans. But engineering has more to learn from Nature than what humans can do. A variety of animal species can fly. Arthropods have the majority of species that can fly but flight has evolved in amphibians, reptiles, birds, mammals and even mollusks and fish. Much can be learned and applied from animal flight to autonomous UAVs. Animals, though considered inferior mentally to humans display amazing cognitive behavior from which much can be learned and applied to autonomy. Many animals have superior sensory perception to humans and biomimicry of their perception also has much to contribute to autonomy.

IV. Applications of Bio- inspired Design to Autonomy

In the following subsections, several examples are presented in which autonomy is inspired by natural systems. This list is not comprehensive but is meant to present a sample of diverse techniques for autonomy that are in some state of research at NASA.

A. Communal Sensor Network

Noise abatement in aircraft engine nacelles is conventionally accomplished by massive numbers of Helmholtz resonators arranged behind the nacelle liner. These resonators are passive as they are of fixed and homogeneous impedance. The impedance is selected as a tradeoff to achieve acceptable noise reduction throughout all periods of the flight regime (e.g., take-off, cruise, and landing), though realizing optimal reduction in none. Also, there are problems in translating design into operational systems as designs are not perfectly implemented in manufacturing and properties can change during use.

Techniques have been developed to adjust the impedance of a resonator *in situ* [20], thus mitigating these problems in design, production, and maintenance while allowing for better noise reduction as acoustic conditions change. Furthermore, it has been proven that heterogeneous liners can achieve better noise attenuation than the optimal homogeneous liner [21]. The question then becomes, how is the decision made to set impedances of each resonator to achieve optimal nose attenuation throughout the flight regime? A conventional approach is to predetermine, through modeling, simulation, and experimentation, the best combination of impedances for all resonators under differing acoustic conditions. Once predetermined, the resonators could be centrally controlled during flight to adjust their impedance as conditions change (i.e., a table lookup). Rather than specify the expected, an alternate approach has been examined [22] that would have the resonators act as a *biological community of organisms*: assess acoustic conditions locally, share information with each other when necessary, and make local adjustments in response to these conditions. From a combination of local decisions and actions, impedances will be adjusted locally from which a global optimal attenuation will emerge. It is not necessary to predetermine conditions as the community of resonators assess and respond to conditions as they change. This may serve as a model for other applications that would benefit from a biomimetic community model.

B. Autonomy of Morphing wings

To achieve the complex maneuvering required of myriad parts for the morphing wing (described in Section II, A) cannot be accomplished by direct human control. Rather, the future of a morphing wing is a complex network of CPSs that is required to take high-level instruction on mission, assess full and constant situational awareness of aerodynamic conditions, apply this awareness to decisions that are based on training, experience, and learning, and effect the morphing of the wing to achieve mission success. The CPS network mimics a bird's wing as an autonomous system.

C. Learn To Fly

NASA has developed a "Learn-to-Fly" concept [23], where techniques are being explored to rapidly and autonomously develop vehicle characterization and control strategies *during flight* with minimum human interaction. As with the morphing wing, this philosophy differs from conventional methods for defining control laws. Rather than specify all control strategies and vehicle characteristics in design, methods are being developed whereby these can be evolved, adapted, and optimized in flight. The biomimetic approach is drawn from the way baby birds learn to fly. While they are born with genetic capability and predisposition for flight, their early flights are erratic and inefficient. From these experiences, better techniques are rapidly developed and adopted until the bird is able to fly efficiently with skill. These techniques go beyond initial determination of rules but will be continually used to adapt for new situations resulting in improved flight.

Early results have developed efficient and rapid flight test capabilities for estimating highly nonlinear models of airplane aerodynamics over a large flight envelope. Used in conjunction with fuzzy-logic system identification algorithms, flight maneuvers result for flight conditions ranging from cruise to departure and spin conditions.

D. System Health Management

Currently health assessment and management of vehicle systems is dependent on direct human decisions and action. Limited information is provided to cockpit displays as input to humans for decision and action. Much dependence is placed on periodic human inspection for fatiguing components or systems needing maintenance or replacement. Scheduled end-of-life replacement is designed to replace components before failure but may result in premature replacement. However, natural systems have developed better means of autonomic immune and repair systems and can serve as models for such automation in machines.

Integrated Vehicle Health Management (IVHM) [24] [25] [26] was conceived to emulate this capability by collecting data relevant to the condition and performance of a vehicle's sub-systems and automate its transformation into information that can be used to support operational decisions. The concept of IVHM has been made possible through the development of inexpensive and small Size Weight And Power (SWAP) electromechanical sensors and communication technologies that allow their pervasive distribution throughout the vehicle to collect data. Such a sensor network enables continuous monitoring and real-time assessment of vehicle functional health, much like an animal nervous system. But beyond collection of information, recent advances in information fusion and artificial intelligence facilitate autonomous decisions. The IVHM vision goes beyond the collection and presentation of data for diagnosis of system health. It includes system prognosis for prediction of remaining useful life of components, recommendations on preventative maintenance, and fail-safe decisions on continued operation. Maintenance operations are improved by reduced occurrences of unexpected faults and by early identification of failure precursors. Condition-Based Maintenance (CBM) is enabled, enhancing mission reliability and safety and optimizing component lifetime.

E. Cognitive, Massively Parallel Computing

To achieve the cognitive decisions required of fully autonomous systems that can reason, learn, and adapt to the unforeseen requires substantial improvement in computing capability. A step in that direction is provided by the Bio-Inspired Technologies and Systems Group at NASA JPL as they develop highly parallel computing architectures and algorithms derived from models of biological neural networks and nervous systems [27]. These systems use aspects of natural selection and seamless integration of sensing, processing, and storage functions to address ill-defined, computationally-intensive problems which are not easily solved with conventional digital serial computers. They also develop custom VLSI electronic and opto-electronic hardware of application-specific architectures. Applications have addressed the processing of massive amounts of sensory data (surveillance functions), and recognition of spatial and temporal patterns in complex, multi-dimensional signals (e.g., data mining, image interpretation, object recognition).

V. The Relationship Between Antifragile Design and Natural Systems

There is a rising global concern over challenges presented in the application of new technologies to the design of increasingly complex systems. Many problems have arisen that may not be solvable with current methods. Cost in terms of money and time of designing, testing, delivering, operating, and maintaining new systems is accelerating at an unsustainable rate. Systems often do not perform as they were intended. There are many new problems for maintenance and operations. When systems fail, it is often difficult or impractical to correct problems and the complexity of designs increases probability of intermittent problems. Much of the added complexity, and exacerbating this problem, is the integration of information technology into mechanical systems: CPS. These problems are not unique to aerospace and are also increasing in many other industries such as manufacturing.

These challenges will not be solved by simply doing what we know how to do now better. Rather, we need to do things we currently do not know how to do. This requires a transformation of engineering practice. In 2010, former NASA administrator, Michael D. Griffin posed the question, "How do we fix System Engineering?" [28] His concern was that failures of important and complex systems continue to occur despite that everything thought to be necessary in the way of process control was done throughout the design process. Mitigation of future failures is attempted by improving the current system engineering process. Griffin concludes that the answer cannot lie in continuing to do more of the same thing while expecting a different outcome. What is needed is a new perspective of design *elegance*. Application of natural systems is one way to provide that elegance.

One facet of this desired elegance in design and one that may address many of these challenges is a change in design philosophy presented in Nassim Taleb's book, *Antifragile: Things That Gain from Disorder* [29]. In design today, requirements are established and systems are designed to meet those requirements: the system is *predetermined*. If requirements are exceeded, the system fails: the system is fragile. Current engineered systems are designed to be fragile to some degree. If the system is stressed beyond the design requirements, it will fail. Efforts focused on how to design more resilient systems are needed but currently the result is pre-determined systems that are simply less fragile. The opposite of fragile, however, is not less fragile. Taleb defines it as as *antifragile*. An antifragile system becomes stronger when stressed.

Failures in modern complex systems are often due to factors in the interactions of components with each other and their environment that are *undetermined*, *underdetermined*, *uncertain*, *unknown*, *unknowable*, or *unforeseen*. For a system to be designed antifragile, it must be able to adapt to these factors. What is needed are new methods producing systems that can adapt functionality and performance *in-situ* to meet the unknown.

Natural systems provide the best examples of such antifragile systems. Muscle and bone become stronger when stressed through activity and exercise. Most tissue repairs itself when injured. Mechanisms such as body temperature control can be viewed as antifragile behavior. There are countless examples of individual and collective behavior that leads to antifragility of the individual, the species, or the collective.

CPSs are the best technology today to enable design of antifragile systems. But, this requires CPSs that are more than prescribed automation (i.e., fragile). Most work today in autonomous systems is prescribed automation. Trust in prescribed automation is determined by evaluation of the prescription. However, this does not account for unprescribed events, which can produce failure. An antifragile CPS must be designed to adapt to the unforeseen, which requires cognitive autonomy. But trust must be developed. How does one trust a machine that can autonomously adapt its behavior beyond a prescription? How does one trust that the machine will improve as it adapts (i.e., become antifragile)? Again, natural systems serve as models that could facilitate these new adaptive methods for antifragility and for trust.

VI. Applications of Bio- inspired Design to Antifragility

Antifragile design is closely relate to autonomy. If an antifragile system can become stronger when faced with adversity, it must be able to adapt. Adaptation can be facilitated by a cognitive, autonomous CPS. Section II, A described a morphing wing as a biologically inspired method of mobility and Section IV, B described how its mobility is accomplished by autonomous systems. Consider also how this type of system contributes to the antifragility of an airplane. Rather than respond with a fixed design to perform in limited ways for flight, the flexibility afforded by the morphing wing allows the wing to adapt its shape *in situ* to changing and unknown *a priori* conditions.

Similarly, Section IV, C, describes the *Learn to Fly* philosophy as requiring autonomy that can reason, learn, and adapt. In meeting its objective to improve flight control as it faces and learns to better deal with aerodynamic conditions, it identifies as an antifragile system. The autonomous diagnosis and prognosis of the system health management capability described in Section IV, D adds to the antifragility of the systems as problems are identified and corrected before they become catastrophic. Section IV, A describes a communal sensor network whose ability to attenuate noise is not prescribed at design time but, rather, it autonomously adapts its ability to attenuate in response to changing acoustic conditions by operating like a biological community. Its ability to autonomously improve its ability to attenuate noise identifies it as an antifragile system. In the following subsections, other antifragile systems are defined that emulate biological systems.

A. Swarming

Swarm is a term that has a variety of definitions. For this discussion, a swarm is a collection of autonomous robots operating for a common purpose that are not centrally controlled. Thus, they must self-organize and cooperate to complete a mission. Another characteristic is that a swarm is composed of large numbers of relatively inexpensive units that are expendable: 80% failure of individuals may still result in 100% mission success. Swarms present great potential for applications such as exploration, direct sensing and surveillance, and disaster relief. For maximum effectiveness swarms cannot be preprogramed for all action but, must be programed such that, as they self-organize and cooperate, they learn from experience and their behavior is adapted to best complete the mission. There are many populations of organisms that demonstrate swarming behavior and there is much that can be learned and applied to robotic swarms.

NASA has plans for implementing swarms for exploration and earth science applications and for application to air traffic management.

B. Self-healing Materials

Aircraft structural design is a tradeoff between strength and weight. Structures such as wings and fuselage must be strong enough to withstand consistently variable stresses yet any more weight added to the structure than necessary decreases performance. Because of uncertainty, the minimum required level is exceeded and yet there is still failure. Exceeding strength to guarantee against failure would result in an aircraft that would not fly efficiently, if at all. Thus, aircraft structures are designed knowing that fatigue will eventually cause failure. Failure, today, is determined largely by visual inspection.

Inspired from biological systems that self-heal after injury, research is now ongoing at NASA into self-healing materials [30] that can autonomously repair damage without human intervention. Such materials could increase lifetime of mechanical systems thus reducing cost and demand for raw materials. If determined early, damage is easier and cheaper to correct. More importantly, these could improve safety of operations. But what if materials could do more than heal damage? What if they could adapt for strength: borrow from areas of less stress to fortify areas under more stress? What if materials could grow in strength in response to stress, similar to how muscles build strength? Such a system would not be designed for resilience to expected stress but would instead be designed to adapt to undetermined stress as it is encountered; it would be antifragile.

VII. Organizational Infusion of Application of Natural Systems

Currently, there is no programmatic focus at NASA providing a top-down inspiration for the use of natural systems (e.g., there is no organization at any level whose title or mission reflects the application of natural systems to engineering). Instead, the examples given are the result of individual or teams of engineers, given an engineering problem to solve, recognizing the benefits that are derived from looking to natural systems and applying these concepts to their solution. Although there may never be such a titled organization, nor need to be, reaching the full potential of natural system application requires a better connection between engineers and the natural system community and a more pervasive recognition of its benefits throughout the engineering community. At NASA, there are efforts underway to improve this connection and influence the engineering workforce in the value that can be attained in looking to natural systems for engineering solutions.

Recently, the NASA Engineering and Safety Center's (NESC) Robotic Spacecraft Technical Discipline Team

(TDT) has funded a 3-member Bio-Inspired Design (BID) team to evaluate and promote the use of natural systems in Engineering. The BID team helped propose and create a Natural Systems Working Group (NSWG) within the International Council on Systems Engineering (INCOSE) in January 2013 and is now preparing to start its own Natural Systems in Engineering Community of Practice (NSE-CoP) internal to NASA to build on that foundation.

The NASA NSE-CoP will build a network of NASA discipline experts, success stories and relevant resource references for NASA applications fed by internal and (mostly) external information. The NSECoP will use a close relationship with INCOSE NSWG to avoid duplication and provide greater sources for information and expertise. They also propose to build a NASA state-of-the-discipline report for this area, last addressed by NASA LaRC in 2002 [31]. That study resulted in documentation of internal and external research and recommendations for future research in materials, structures, guidance and control, aerodynamics, systems engineering, in-situ resource utilization, and biomimetic systems. Eventually the group expects that NASA's traditional System Engineering processes will expand to more routinely and appropriately ask: "What can we learn from nature that will help us do our job?"

VIII. Conclusion

Some past and present successes have been presented and opportunities for future success have been identified. A relationship is described between the rapidly developing and very important strategic direction in aerospace, *autonomous systems*, and the opportunity for significant progress through the application of natural systems concepts. The philosophy of *antifragile design* and its relationship to natural systems has been defined and, natural systems have been suggested as a means to realize antifragile systems. Several NASA missions that may benefit from application of natural systems concepts were presented with specific examples of past, current, and future applications of natural systems concepts to engineering challenges.

The examples presented are not comprehensive of all of NASA's application of natural systems but does reveal the depth of diversity in current and potential influence in engineering design. Some efforts at NASA to formalize and change engineering to include natural systems concepts as inspiration in the system engineering process are progressing but, to reach full potential, looking to natural systems for design inspiration must become a standard method in systems engineering. Application of concepts from natural systems will not solve all problems but should be a very important part of the engineer's toolbox.

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Auto-Gopher 2–a biologically inspired deep drill for planetary exploration

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Situation

A key objective of NASA's solar system exploration of planetary bodies is the search for preserved bio-signatures and habitable regions. In recent years, various biologically inspired approaches at a range of technology readiness levels have been investigated and developed throughout NASA, industry, and academia. The efforts include artificial nose that was tested on the International Space Station, a biomimetic optical sensor for real-time measurement of aircraft wing deflection, artificial muscles as actuators of biomimetics systems, parallel processing algorithms, as well as snake like robotic device that can reach through narrow openings and passages to conduct investigations. The focus of this brief is on planetary deep drilling. Generally, drilling is a well-established capability on Earth, however, planetary drilling has many challenges resulting from the limited system mass, power, and energy as well as extreme environment that can include low or high pressure and temperature as well as low gravity [Bar-Cohen and Zacny, 2009].

Approach

A wireline, deep, rotary-percussive corer, called Auto-Gopher, has been developed to meet NASA in-situ exploration objectives, whose design and mechanism were inspired by the biological gopher with respect to penetrating soil and debris removal. Like the biological gopher, the Auto-Gopher is launched into the subsurface to create cuttings and cores and removes them to the top surface. The repeated sequence of "carving" and removing process allows forming extended holes in the subsurface. In the case of the biological gopher, tunnels are formed; while in the case of the Auto-Gopher, straight down boreholes are formed. The Auto-Gopher drill is driven by a piezoelectric actuated percussive mechanism. The drill is essentially suspended on a tether and all the motors and mechanisms are built into a tube that ends with a drill bit. The tether provides the power, data communication, and the mechanical connection to a planetary platform on a surface. Upon reaching the target depth, the drill is retracted from a hole by a pulley system.

Results/Benefits

Initially, an Ultrasonic/Sonic Gopher (USG) was designed with a percussive mechanism for sampling ice and was demonstrated in 2005 to reach about 2 m deep in the top ice layer in Lake Vida, Antarctica (Figure 1). The lessons learned suggested the need to augment the percussive action with bit rotation in order to maximize the penetration rate [Badescu et al, 2007]. The first generation of the rotary augmented drill has been demonstrated in a field test to reach a 3 m depth in gypsum. In this drill test, a separate mechanism was used to break-off the cores and remove them. In Figure 2 this drill and the acquired cores are shown. A fully autonomous drill which performs coring, core

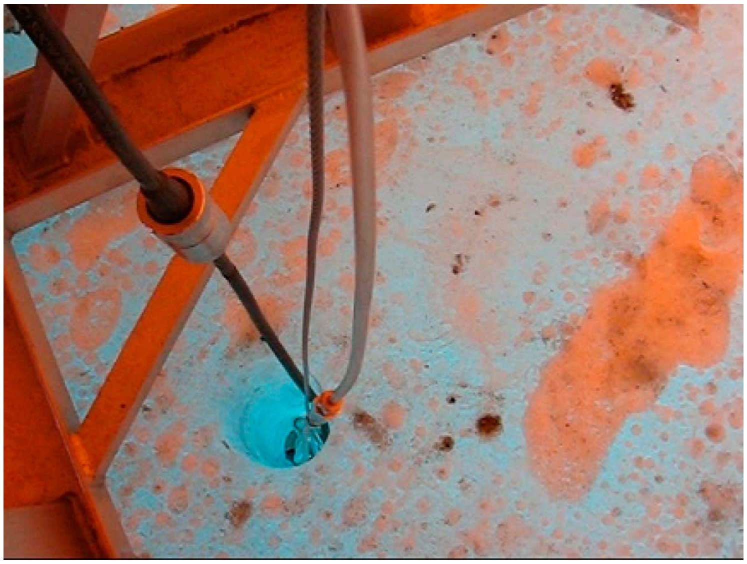

Figure 1 The borehole with the penetrated USG (~2 m deep) at Lake Vida, Antarctica

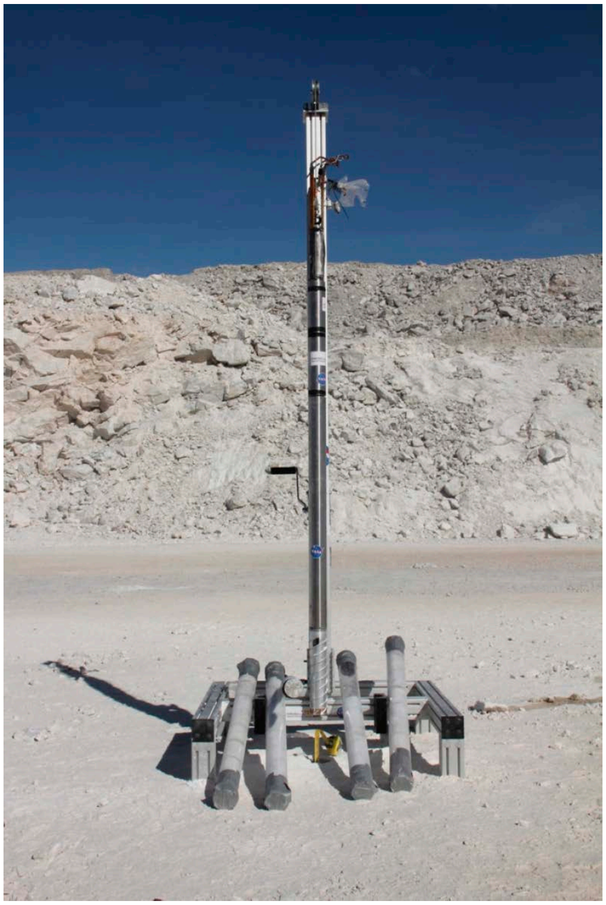

Figure 2 Photo of the Auto-Gopher-1 and the acquired cores from drilling 3 meter deep in gypsum.

break-off and retrieval, called the Auto-Gopher-2, is currently being developed. The drill can be operational at cold environments on Mars, Europa and Enceladus.

This planetary bodies were specifically called out in the latest Planetary Decadal Survey (Vision and Voyages for Planetary Science in the Decade 2013-2022), for future exploration because of the presence of aqueous regions. An illustration of the drilling system that is being developed is shown in Figure 3.

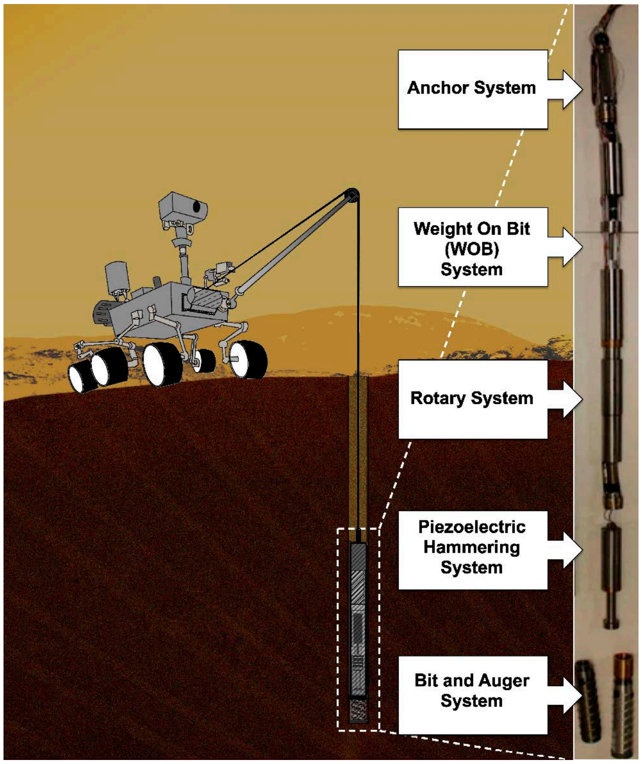

Figure 3 An illustration of the Auto-Gopher concept of wireline deep drilling.

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Biographies

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Kris Zacny is a VP and Director of Exploration Technology at Honeybee Robotics. His expertise includes robotic terrestrial and extraterrestrial drilling, excavation, sample handling and processing, geotechnical systems, and sensors. Dr. Zacny received his PhD (UC Berkeley, 2005) in Geotechnical Engineering with emphasis on Mars drilling, ME (UC Berkeley, 2001) in Petroleum Engineering, and BSc cum laude (U. Cape Town, 1997) in Mechanical Engineering. He participated in several Arctic, Antarctic, Atacama, Greenland, Mauna Kea, and Mojave drilling expeditions. Dr Zacny has over 150 publications and managed over 100 NASA and DoD funded projects.

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Hyeong Jae Lee is a member of the Technical Staff at JPL's Electroactive Technologies Group, and received his B.S. and Ph.D. degrees in Materials Science and Engineering from The Pennsylvania State University. Prior to joining JPL, he has worked on research projects related to ultrasonic transducers that are needed for medical imaging and underwater sonar. Following his Ph.D. degree, he joined JPL, where he extended his research into practical applications that are needed for robotic exploration, such as planetary sampling and ultrasonic deep drilling to enable acquiring samples from various planets under harsh environments.

Stewart Sherrit received his B.Sc. in Engineering Physics (Nuclear-Mechanical option), M.Sc. (Solid State Physics-Thermoelectric Conversion) and PhD (Physics: Characterization of losses, dispersion and field dependence of piezoelectric materials.) from Queen's University, Kingston. Canada. He is a senior member of the technical staff at JPL working in the NDE& Advanced Actuators (NDEAA) laboratory. He has authored 9 book chapters, over 140 papers, 61 NASA Tech Briefs and 88 New Technology Reports, and 12 patents. His current research is in the novel implementation of actuators and sensors for space.

Xiaoqi Bao is a Senior Member of the Technical Staff at the Jet Propulsion Laboratory. He joined JPL in 1997 after serving for ten years at Pennsylvania State University. He received his Ph. D., Physics, in 1985 and M. Sc., Physics, in 1982 from the Chinese Academy of Sciences, Beijing, China. In 1986, Dr. Bao was a Visiting Scientist at Toyama University, Japan. His R&D area includes sensors and actuators involving piezoelectric, electroactive and SMA materials with applications in aerospace and other industries. He has published more than 100 papers in related areas.

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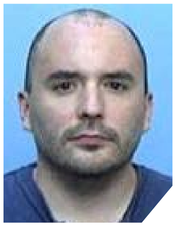

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Leveraging Nature's Gifts in the Design of Control Systems

Mark Kerbel, CTO & Co-Founder, Encycle Corp.

Abstract

We often attempt to solve problems in such fields as control systems and energy usage using known top-down control structures, whereas collectives in nature communicate and carry out their activities using far more elegant, simple, and efficient constructs. This paper outlines the inspiration and process by which a commercial application in the field of peak electrical demand management was developed, including unexpected lessons and benefits unforeseen during the product's conceptualization.

Introduction

Many are intrigued by the concepts and benefits espoused by biomimicry, but often wonder how – or even if – biomimicry can be applied to their existing work. A skeptic can, no doubt, always find a reason to not try something new, but someone who is technically minded, and more importantly, curious, would find the challenge of applying new problem solving techniques to be an enticing pursuit.

The following is a discussion of the travels taken on one such adventure, whereby the initial excitement of discovering biomimicry eventually lead to the creation of a commercially viable product, and the product's biomimetic attributes are highly regarded in terms of marketing cache. The story of this product's invention is meant to inspire others to similarly engage in serious thought with respect to utilizing biomimicry within their own practices. The discussion will focus on the experiences of the author using biomimicry to create a new style of building control system, but not on the specifics of the invention. Those interested in learning more about the invention can review the author's published patents and material on the web site of the author's company (See *About the Author* below).

It *is not* the author's intention to portray his experiences as truly unique. Far from it, similar inspiration and positive developments have no doubt been experienced by others who have had the joy of watching a bio-inspired technology move from the drawing board to a live device, put to use to benefit the world.

It *is* the author's intention to specifically motivate engineers to use biomimicry as a core element of their design efforts and enjoy the many resulting benefits.

Once upon a time…

The author's first introduction to the world of biomimicry occurred when a friend mentioned a book describing emergent systems, a principle that seems to crop often in nature, including animals, insects, brains, and even cities (Steven Johnson's, *Emergence: The Connected Lives of Ants, Brains, Cities, and Software*, ISBN-13: 978-0684868769). Emergent systems are those where organisms communicate with each other by exchanging small bits of information frequently, and over time through mutations, evolve behaviors (i.e. decision algorithms) that are not only efficient for each organism, but more importantly, are effective for the collective's survival even under varying environmental conditions. Notice how decentralized decision making is a key aspect of such systems, where no 'master & slave' control structures are required, and are in fact, highly discouraged.

The concepts and examples cited in the book were so intriguing, that the author and a colleague (Roman Kulyk, the fellow co-founder of Encycle) attempted to find an application for emergent systems in their activities at the time (developing transaction clearinghouse software systems for the utility sector). Alas, application was found, so emergent systems were parked in the back of our minds as an intriguing concept, where perhaps eventually, it might become relevant one day.

It is worth noting that at the time, the inventors were not even familiar with the term Biomimicry. They were introduced to biomimicry much later, when it was pointed out Janine Benyus (who coined the term in her book *Biomimicry: Innovation Inspired by Nature*, ISBN-13: 9780060533229, and co-founder of the Biomimicry 3.8 initiative), cited Encycle's Swarm Logic in her TED talk as an example of biomimicry.

Hey, Wait a Minute…

Fast forward a few years later, and these same individuals found themselves in the situation of starting a new venture with a clean slate and only 1 admittedly very lofty goal: Derive some type of invention that would simultaneously be good for the planet while financially attractive for its customers. A simple and structured process was initiated, starting with 10 real world problems phrased as questions about energy. One of those questions was "As a commercial building operator, how can I reduce the peak electrical demand charges on my monthly utility bills?" Note that unlike residential electricity consumers who only are billed consumption charges (i.e. kWh used over the course of the billing period), commercial & industrial consumers also pay for peak demand charges (i.e. the maximum, say, 15-minute, kW observed during the billing period).

After spending a week of interesting but potentially never-ending exploration of the problems, the two decided to pause their research and review the 5 topics investigated in depth to date. When reviewing the question cited above, it struck both researchers that perhaps emergent systems principles could be used if one could allow electrical loads to communicate with each other, and create simple yet highly efficient algorithms such that each load understood how to operate efficiently as part of a group. One of the team member's background in implementing building automation systems lead to the belief that this could greatly minimize the custom engineering activities required at each building under conventional technologies and techniques. Interestingly, the two other most promising concepts reviewed at the time also made use of the "smaller – and decentralized -- is better" metaphor. Perhaps the principles of emergence are valuable across different applications than originally anticipated by the inventors, but exploration of those other concepts was halted in favor of the most promising one.

A Novel or Crazy Idea?

Surprisingly, when the author contacted academic experts in the field of emergence, attempting to find real-world, tangible applications embedding the concepts, he was taken aback to hear that not only did they claim that beyond a few software simulations, nothing had been developed yet, but this was primarily due to the belief that the principles were not sufficiently mature upon which to create applications. Ironically, this encouraged even more of a challenge to develop the concept, in a race to develop the first biomimetic product in the energy controls field.

When speaking with building controls experts, it became clear that there was tremendous skepticism if the concept of a completely decentralized, "bottom up" decision making control system could even work. Most importantly, a search across the industry did not reveal anything even remotely close to the idea of allowing a collection of electrical loads to work independently yet towards a group-based goal.

Biomimetic Novelty as an Asset

The novelty of using a control system found in nature unknowingly became the company's key driver of interest in the media, as well as energy & sustainability circles in Toronto, Canada (where the company was founded and continues to operate one of two R&D offices). The simplest analogy used by the author to describe the control system was a bee hive, where the queen bee does not instruct each bee, rather, each bee senses the pheromone trails of others and the hive's environment, and makes decisions using algorithms evolved over millennia. These efficient decision algorithms are used continuously by each bee, making independent and autonomous decisions that are not only useful for each bee's survival, but also beneficial for the hive's survival. The analogy of replacing bees with electrical loads, and those loads broadcasting wireless messages to each other instead of emitting pheromone trails, and those load making decisions of when to operate that are not only good for its own purposes, but also good for the building as a whole, was readily grasped by reporters eager to publicize such a nature-to-engineering concept. In fact, the bee analogy was the centerpiece of the company's first article in a public media source[1], and continues to be the analogy used to explain the invention, leading to the company coining the term Swarm Logic to name the derived control strategy. The concept's commercial uniqueness and patentability also drew the attention of public research funding agencies as well as investors.

A lesson that can be learned from this experience is that a biomimicry-motivated invention can inspire confidence, given the public's general impression that nature has proven to be creative in terms of crafting sustainable organisms and systems. Moreover, the innate appeal of nature, which has developed highly efficient and stable processes to not only control systems, but also perform tasks such as build new objects or store energy, enhances a positive perception of the otherwise cold, inanimate world of engineering. One should not underestimate the ability to capture attention and build excitement by participants who truly want biomimetic applications to succeed.

It is the author's opinion that the first biomimetic application in the energy efficiency industry derived attention *specifically because it was a bio-inspired concept* with strong commercial appeal.

The Gift that Keeps on Giving

The initial benefits of independent, distributed, and adaptive decision making within the realm of peak electrical demand are numerous:

- Control systems that can make intelligent decisions based on very little data allow the use of few and inexpensive sensors per node, rather than mandating complex and costly gear that may require specialized technical skills to install as well as calibrate over the equipment's lifetime.
- Control systems that require very small packets of data and can even operate without perfect real-time knowledge of all nodes in the collective permit the use of lightweight communications networks, where perfect knowledge comes at the price of complexity and higher equipment costs.
- Control systems that permit each node to adapt to its changing circumstances allows group optimizations to occur that handle the inevitable fluctuations in the real world without the entire group needing to know of such local circumstances.
- Control systems that can detect and rapidly adapt to the addition or removal of nodes from the collective and rebalance as a group under the new environment are tolerant of faults that will occur from time to time.

Each of these benefits has been validated under successively improved versions of the control system.

The larger surprise was how often the control methodology was found to be very useful in terms of solving additional problems in other unanticipated manners. During the initial concept's derivation, it was only anticipated that one, solidly focused and defined application (and an associated single patent) would be derived. This was later observed to be a gross simplification of the extensions available to the initial concept (and its broader patentability).

For example, the decision algorithm requires that each node perform basic sub-metering of its load under control. This was viewed as a minor aspect of the invention, but certainly not viewed as a valuable feature initially. As the product was developed and used by pilot customers, the first observation was that sub-metering data was highly valuable in terms of not only controlling peak demand, but also observing wasted consumption (typically not during the expected hours of a building's highest demand period). The control system was therefore adapted to reduce not only peak demand and hence peak demand charges, but similarly, reduce the other major component of commercial buildings' electrical bills, namely consumption charges.

Another major revelation was usage of the control system for an entirely unanticipated application. A demonstration of 3 prototype "black box" devices (Figure 1), each connected to small fans, was laid out on a meeting room table and provided to the management team at a large utility's energy services organization. When the inventors demonstrated the

[1] "Lots of buzz surrounding this company", *Tyler Hamilton, The Toronto Star, Sep 3, 2007, http://www.thestar.com/business/tech_news/2007/09/03/lots_of_buzz_surrounding_this_company.html*

Figure 1 Gen 0 black box prototype (black), Gen 1 pilot device (white), Gen 2 production device (blue)

ability to wirelessly change control strategies and within seconds, observe the fans changing their behavior, Chris Tyrell, president of Toronto Hydro Energy Services at the time, indicated interest in using the invention for the service territory's upcoming Demand Response program. The inventors did not even know of the concept of Demand Response, a style of utility program where consumers are compensated for reducing their electricity usage when asked by the utility (typically under periods of high stress such as the afternoons of very hot days, although also valuable for other economic and reliability purposes). Upon further investigation, not only were the decentralized decision algorithms able to implement the functionality required for Demand Response programs, they also brought about benefits previously unavailable from conventional techniques without tremendous complexity and custom-engineering: At the end of Demand Response events, conventional building control systems resume their normal operation which typically results in rapid increases in demand, often to the point of setting a new maximum point for the current billing period. While such spikes in demand may only last for less than an hour, most utilities assess monthly peak demand values based on 15 minute increments. The net result is that the building operator receives some credit for curtailing demand during a requested event, yet can encounter such high demand charges during the same billing period that it wipes out any financial benefit. The pain is felt not only financially by the building operator, but also by the utility, whom must brace for the impact of post-event rebounds across its service territory. The Swarm Logic strategy not only reduces peaks before and during Demand Response events, but also allows for a graceful exit that avoids any rebound effect.[2] The inventors were not even aware of such utility programs when the control strategy was derived, and yet the control strategy's Demand Response benefits have become one of its most commercially attractive features.

Further extensions of the control strategy have been created to solve other types of utility/grid problems, again, unanticipated during the strategy's invention. For example, grid operators must maintain grids within certain frequency tolerances, and accordingly, offer programs to those that can help stabilize the grid when more or less demand is required within short notice (often 4 seconds). An extension to the Swarm Logic methodology was derived to follow such signals from the grid operator and distribute the needed increase or decrease in demand across multiple buildings, requiring only minor perturbations from normal behavior at one node in each collective.

The Road Ahead

The concept of electrical loads communicating with each other to optimize a building's peak electrical demand has grown from a whiteboard exercise in 2005 to a patented technology, deployed in hundreds of buildings across the U.S., Canada, and even Japan. Almost all of the initial biomimetic attributes contemplated have been implemented in the product set. The only facet of emergent systems that was not implemented was that of genetically breeding

[2] Additional benefits in terms of improved interior comfort maintenance and accurate load shed exist, but the primary focus of negating rebound is the most pronounced benefit from a control strategy perspective.

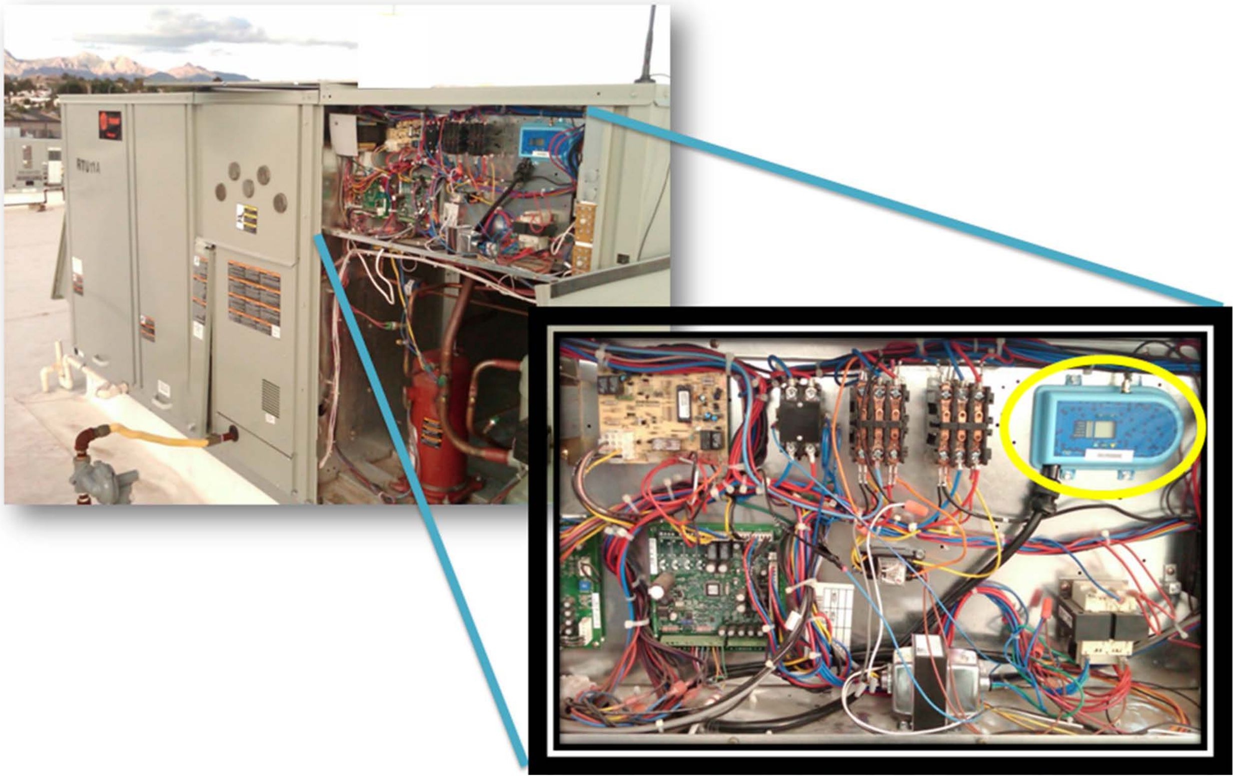

Figure 2 Typical Field Installation of an Encycle Controller

algorithms (rather than crafting them by hand). The challenge to develop and test genetically bred algorithms lay in terms of limited resources to attempt this activity, given that the initial development team comprised of two people who handled other functions beyond R&D. It would be interesting to revisit this topic one day, and see if (or more likely, how) genetically bred algorithms could perform better than the current algorithms. In retrospect though, the hand-crafted algorithms were not exceptionally difficult to derive, and over the course of 10 years, very few changes have been implemented to improve performance.

The technology's benefits have been proven through review by utility-sponsored energy auditors, by building operators experiencing very meaningful reductions in their energy costs, and utilities using the technology to reduce demand when grid reliability requires such measures in short order (See http://www.encycle.com/who-we-help/ for case studies at 4 installations, spanning different types of buildings). With sustainability increasing in prominence in the corporate world, as well as the constant desire for energy efficiency and cost savings, there is no shortage of demand for this bio-inspired technology.

While the existing technology platform (Figure 2) continues to be enhanced and deployed in an every-growing population of buildings, there are far more exciting trajectories for this bio-inspired control strategy: In true biomimetic fashion, the control strategy is migrating to find new "homes", operating on an even broader set of controls equipment, including native integration with smart thermostats and building automation systems, with broader applications for energy storage devices, electric vehicles, and all forms of electrical appliances and loads.

For those unaware of events in the utility sector, the mass-deployment of renewable energy generation such as photovoltaic panels and wind turbines, combined with the growth of energy storage technologies, presents a challenge to grid operators who favor stable and predictable demand patterns over wildly swinging fluctuations that may occur at different locations in their grids. Using a control strategy that not only optimizes demand for a very large collection of nodes, but can also implement different variations of the strategy in smaller decompositions of those nodes (to achieve different local goals) could allow one to optimize very large problems without resorting to conventional command-and-control strategies that require far too much real-time data from all elements of the grid to be practically managed. After all, the world manages itself as a collection of self-organizing ecological and biological systems without the need for one master control element and full knowledge from "top to bottom".[3] This could lead to the biomimetic invention at hand being used to derive benefits for more than one building at a time, but extended to entire grids.

This may eventually lead to the adoption of the bio-inspired control system as a highly desirable and eventually commonplace energy control strategy… all because of bee hives.

Biomimicry as a Design Philosophy

Biomimicry practitioners have cataloged biomimetic aspects found in nature in terms of design patterns. These patterns can be readily applied to engineering problems. For example, a crane designer could decompose a crane in terms of a set of components that are meant to grasp, lift, and move objects from one location to another, and then final analogous elements in nature that perform similar operations using completely different systems and techniques. The designer's goal would be to find inspiration for substantially lighter components, or perhaps highly efficient mechanisms that can grasp and move objects using minimal materials and energy.

The process of examining nature as one's design inspiration leads to an unintended benefit: It teaches one to continuously strive to be as efficient as possible. Mimicking nature's abhorrence of waste (wasted materials, wasted energy, wasted communications) leads to a philosophy that prizes simplicity as the ultimate elegance in design. The practical aspect of this design philosophy causes one to seriously question the addition of each feature to a product: Is this truly going to create a worthwhile benefit, and even if so, is there a simpler way to design it? While it is easy to endlessly add "bells and whistles" to products, it requires discipline to always examine why features are being added, either removing some or else finding more efficient ways to add truly beneficial ones. It eventually becomes second nature for product engineers to think in terms of the simplest possible design as the attractive alternative and immediately recognize overly complex features as undesirable (and rethink them in terms of simpler constructs).

Using the design patterns and design philosophy of biomimicry naturally (pun intended) leads to a rather fulfilling sense of accomplishment. Looking back at the elegance and simplicity of one's designs under the influence of nature, particularly in contrast to what one might have designed without such inspiration, is a highly motivating and positive experience for any engineer. The author can personally attest to the enjoyment one receives from informing others of bio-inspired design and invention, and seeing others similarly motivated to follow such practices.

It may take time to train engineers to innately think in such terms, but it is well worth it. Teaching biomimicry concepts is a captivating and exciting way to catch engineers' attention to understand an enhanced design philosophy. It would be wise for all engineering programs to tech biomimicry at the start of every core curriculum, thereby raising an entire generation where the norm is to strive to design as efficient as possible inventions, with graduates innately starting every design process with a search of relevant biomimetic patterns and nature's inventions.

Educators periodically refresh engineering course material, and look for topics that students may find captivating. One could consider adding biomimicry to courses, presenting it as a novel design philosophy that may catch engineers' attention.

Acknowledgements

The author wishes to thank not only his co-inventor of the biomimetic swarm logic concept, Roman Kulyk, but also the many supporters of the concept including his family members, early stage angel investors, later stage institutional investors, public funding agencies, and of course, the employees who helped bring the concept to fruition as well as the customers with the foresight to deploy a novel concept in their buildings, and finally, the utilities and industry partners who encouraged the adoption of the technology.

About the Author

Mark Kerbel is the Chief Technology Officer and Co-Founder of Encycle Corp. (formerly named REGEN Energy), and co-author of the company's patents. Mark is a key member of the technology's

[3] See James Lovelock's writings on the Gaia theory of earth as an organism, http://www.jameslovelock.org/

design team, and has spent more time on the rooftops of buildings in Canada and the U.S. during the company's early years than he would like to recall, developing the company's biomimetic inventions. Mr. Kerbel is based at the company's San Marcos, CA offices, and evangelizes Swarm Logic's ability to enhance grid stability and reduce building operator's energy costs. Encycle and Swarm Logic are trademarks of Encycle Corp.

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Design of a Bio-inspired Optical Current Transducer

By Jacquelyn K. Nagel and Steve E. Watkins

Abstract
The natural world provides numerous cases for analogy and inspiration in engineering design from simple to complex cases. Biological systems often reveal sustainable and adaptable design principles. This research presents a function-based, biomimetic design method that is used to generate and evaluate bio-inspired sensor designs. The natural design of biological systems is examined from an engineering context using functional abstraction and representation. In this paper, the systematic method is applied to a current sensor re-design that is based on magnetically-sensitive chemical reactions found within birds. A novel approach to the standard optical current transducer is described.

1. Introduction

The natural world can be a source of inspiration for engineering design from simple cases such as hook and latch attachments to articulated-wing flying vehicles. The commonality between biology and engineering may not be obvious, and engineers may not have the needed background or awareness to connect these domains easily. A systematic method of functional abstraction and representation, such as the approach described in this article, can facilitate biomimetic investigations. Sensor technologies and systems are active areas for research and sensor design is often interdisciplinary. As such, it is a particularly rich area in which to apply the biomimetic design methodology.

Biological organisms operate in much the same way that engineered systems operate, each part or piece in the overall system has a function, which provides a common ground between the engineering and biology domains. Borrowing ideas from another discipline during design allows nature to guide the process. Utilizing concepts from a non-engineering domain such as biology has shown to spark inspiration and innovation for a variety of technologies, materials and systems [1-5]. Bacteria, plants, insects, mammals, retiles, etc. have diverse form and function, but their adaptive and elegant methods of sensing and communication can provide engineers with ideas for new sensors as well as improvements to current sensor designs [6-8]. Adapting features and characteristics of biological systems can significantly advance engineered systems, including sensors, which has resulted in novel designs and improved sensor technology [6, 7, 9-19]. Furthermore, bio-inspired sensor design is an emerging branch of research, and offers potential advantages over traditional sensor technology [19].

The biological domain provides inspiration at many levels, such as cellular, organism and species. For instance, if a system-level sensor design is desired with consideration of details for interfacing, communication, or packaging, one can study the interaction of one species with another or look to any ecosystem for ideas. Not only is nature rich with sensing methods, but also it provides strategies associated with the use of those sensing methods. Additionally, biological systems typically exhibit low energy requirements, high sensitivity, and redundancy [20-22]. Furthermore, they exhibit parallel sampling and processing of sensory information by having tens or even hundreds of receptor organs in parallel, each containing dozens of receptor cells, which improves the signal-to-noise ratio through averaging [6, 23]. This also reduces the likelihood of error due to loss of or failure of a receptor organ. A great lesson from nature is redundancy; in most biological systems there are many instances of redundancy due to the specialized application of each sensor. Biological systems provide insight into adaptable design, which often leads to designs that are more elegant, efficient, and sustainable.

A function-based, biomimetic design methodology is applied to electrical current sensing problems. Current transducers (CTs) are used in the electrical power industry to monitor and control line conditions [24-25]. Similar current monitoring is required for power electronics that support applications in robotics, aerospace, etc. [26]. Conventional designs that are magnetic-core based structures are cost-effective and well-understood; while the design of optical current transducers (OCTs) that are based on the Faraday effect address high-end power-quality requirements [24-28]. Neither technology is ideal with limitations in cost, complexity, sensitivity, range, etc. This article details the conceptual development of an optical current transducer design following a biomimetic design methodology that aims to address the stated limitations and reduce the complexity of the optical design.

2. Optical Current Transducers

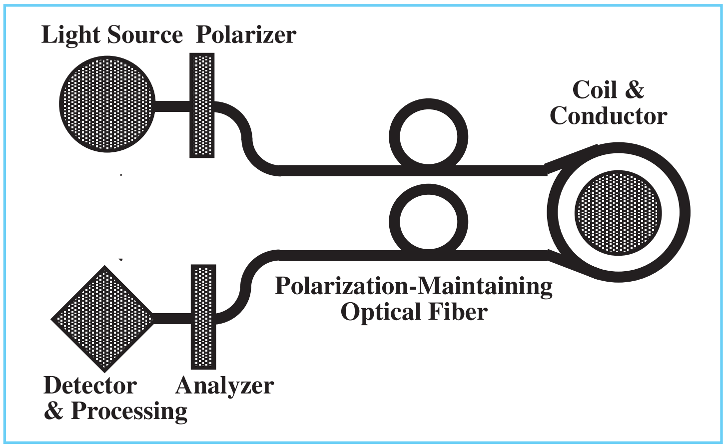
Current transducers (CTs) monitor alternating current in electrical transmission systems. Typical applications are to provide measurement, metering, control, or safety capability for high-current transmission systems. The output of the CT is a current that is proportional to the primary current and is matched to the requirements of the application instrument. The basis of operation is Ampere's law in which the integrated magnetic field around a closed loop is related to the current through the loop. This arrangement provides electrical isolation of the primary circuit and the CT circuit.

Critical characteristics of CTs include cost, calibration, sensitivity, and dynamic range. For simple applications related to measurement, metering, and fault protection, performance requirements may be moderate. For advanced applications, performance requirements are more difficult to meet. For instance, limitations in dynamic range and sensitivity may hinder effective measurement of high-current systems and transients situations and may prevent effective characterization of transients, phase conditions, and steady-state harmonics. Such latter applications are becoming more prominent with the introduction of smart-grid technologies and the increase in distributed power generation. Precise, real-time measurements are required in order to maintain power quality.

Conventional current transducers use a toroidal iron core to concentrate the magnetic field. The primary current conductor passes through the toroid, or has limited windings, and the transducer circuit is linked to secondary windings around the core. While the design is robust, the performance of such CTs suffer with respect to dynamic range and sensitivity, e.g. due to core saturation. Optical current transducers (OCTs) have been developed that rely on the Faraday effect in which the polarization of light is rotated due to the current-induced magnetic field [24-28]. Typical systems have a Faraday-effect sensor head made of either bulk glass or optical fiber and the transmission from the primary line to electronic instrumentation is via optical fiber. Such devices are immune to electrical interference effects, are isolated from the primary line, and have excellent dynamic range and sensitivity. The instrumentation and calibration are more complex compared to conventional CTs. Mechanical, vibration, and temperature errors can be problems. Also, the light wavelength characteristics of the optical source must be well characterized.

For one all-fiber version of the OCT, the system consists of a sensor head made of a coil of optical fiber, two transmission optical fibers, polarization control, laser source and photodiode, and electronic instrumentation as shown in Figure 1 [25,27,28]. Current –induced

Figure 1 A Conventional Design for an All-fiber OCT.



polarization changes are converted to a light amplitude change through precisely aligned input and output polarizers. Polarization-maintaining fiber is needed for the sensor head and the transmission path. Temperature compensation is required, since temperature changes in the sensor head and the transmission fiber can affect accuracy. Due to cost and robustness concerns, OCTs mainly tend to be used for applications that require the highest accuracy and performance.

3. Biomimetic Design

3.1 Commonalities between Nature and Engineering

The basic concepts behind sensory physiology and morphology, the fundamental principles and structures of how biological systems relate to their environment, can be adopted as a working model to construct different types of sensor designs. Further, one can consider if direct or indirect mimicry is appropriate for a new design. Meaning not all bio-inspired sensors function identically to the biological system being mimicked. Once the biological system is understood, the engineer can decide if directly copying the biological design or mimicry through analogy is the best course of action. Both types of design have been successful and have lead to innovations in sensor design. The biomimetic design method presented in this article aims to inspire more than mechanical and electro-mechanical devices. This research challenges traditional engineering design theory and methodology, which has been reserved for mechanical and electro-mechanical designs to also include purely electrical designs (e.g., sensors) [29].

For biomimetic design, consider the physical and non-physical aspects of biological systems. Researchers discovered [30,31] that biological organisms have three outlets for interacting with a changing environment: physiology, morphology, and behavior. A biological organism will adapt new functionality (physiology) or structure (morphology), or learn a new behavior to obey the instinctual actions of reproduce, protect, and sustain life. Additionally, researchers noticed similarities (e.g., change shape, expose pores, drop offshoot) across multiple biological ranks (i.e., kingdom, phylum, class, order, family, genus, species) that were initiated and carried out for dissimilar reasons; these are termed strategies. Thus, four biological categories to consider when developing a biomimetic design are [30-33]:

- Physiology: concerned with the vital functions and processes of biological systems. (non-physical characteristics)
- Morphology: concerned with the form, structure, and the associations amongst the physical characteristics of a biological system. (physical characteristics)
- Behavior: the sum of the responses of an organism to internal or external stimuli. (non-physical characteristics)
- Strategy: a generic behavior, function, or process that is exhibited among multiple biological ranks to achieve different goals. (non-physical characteristics)

A formalized methodology and associated tools have been developed for biomimetic design [34, 35]. A summary of the method is given in the following section.

3.2 Biomimetic Design Methodology

Using functional representation and abstraction to describe biological systems presents the natural designs in an engineering context and allows designers to make connections between biological and engineered systems. Thus, the biological information is accessible to engineering designers with varying biological knowledge, but a common understanding of engineering design methodologies. By creating a bridge between the two domains through the perspective of function, engineers can leverage the elegant designs found in the world around them [36]. To facilitate an efficient and general process, a systematic methodology is used that follows a problem-driven path. As a function-based method it assists with reducing fixation on aesthetic features or a particular physical solution, allows one to define the scope or boundary of the design problem as broad or narrow as necessary, and facilitates exploration of the design space outside traditional areas of knowledge.

The five-step design methodology is summarized in Table 1 [34]. The process begins from customer needs or an identified problem to solve, which are used to define a black box functional model. Next the designer is instructed to decompose a functional model from a black box model, resulting in a conceptual functional model. The conceptual functional model describes the desired functionalities of the solution and is used to query the engineering and biology knowledge bases.

Table 1 Steps of the Bio-inspired Design Methodology

Step	Description
1. Define Problem	Define the problem to be solved, gather a set of needs or requirements, and map them to important flows.
2. Decompose	The problem is decomposed into, first, a black box model and, second, a functional model.
3. Query	Knowledge bases are queried to identify solutions to the function/flow pair(s) of the decomposed models. Two knowledge bases are required: one containing engineered systems and the other containing biological systems. Both are indexed by engineering function and flow.
4. Make Connections	Connections are made through analogies, metaphors, first principles, or biological functional modeling to assist with making the leap between the biology and engineering domains.
5. Concept Generation	Concept generation is performed to create bio-inspired conceptual designs. Concept synthesis involves analysis, reflection, and synthesis. Analysis is on the returned engineered and biological solutions from Step 3. Reflection is on the connections to the engineering domain formulated in Step 4. Synthesis is of the existing engineering solutions, engineering solutions inspired by biology and inventive solutions inspired by biology to derive a new design.

Query results are then analyzed for connections with a potential solution to the problem. Connections are formulated through analogies, metaphors, first principles, or biological functional modeling of physical and non-physical biological characteristics. The final step in the methodology is to synthesize the connections formulated between biology and engineering into conceptual designs. The lexicon and query tools as well as representative studies are described in the references [37, 38].

4. Bio-inspired OCT Re-design

The conventional optical current transducer (OCT) is based on the Faraday effect. A bio-inspired re-design, based on the prior methodology, can be made which stems from the magnetically-sensitive chemical reactions found within birds.

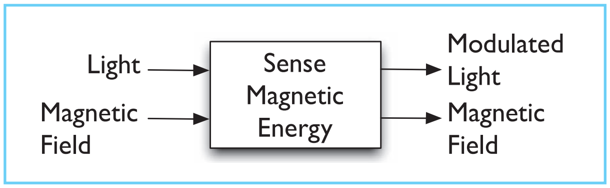
4.1. Define Problem

The objective of the OCT re-design is to lessen sensitivity to temperature, wavelength, and vibration. Modulating amplitude instead of polarization of light will make the device overall easier to install and calibrate. These needs are derived from the limitations of current OCT designs. These needs are mapped to flows as shown in Table 2 to complete the first step of the methodology.

Table 2 OCT Needs Mapped to Conceptual Flows.

Need/Constraint	Functional Basis Flow
Modulated light	Optical Energy
Less sensitive to temperature, wavelength, and vibration	Magnetic Energy

Figure 2 Black Box Functional Model of OCT.



4.2. Decompose

Next, a black box model and a conceptual functional model of the OCT are created. The black box model guides the decomposition of the flows into a functional model. The black box model of Figure 2 demonstrates that the overall objective of the design is to sense magnetic energy. The decomposed conceptual functional model from the black box and needs mapped to flows is given in Figure 3. Functional modeling shows the generalized form of energies

Figure 3 Decomposed Functional Model of OCT.

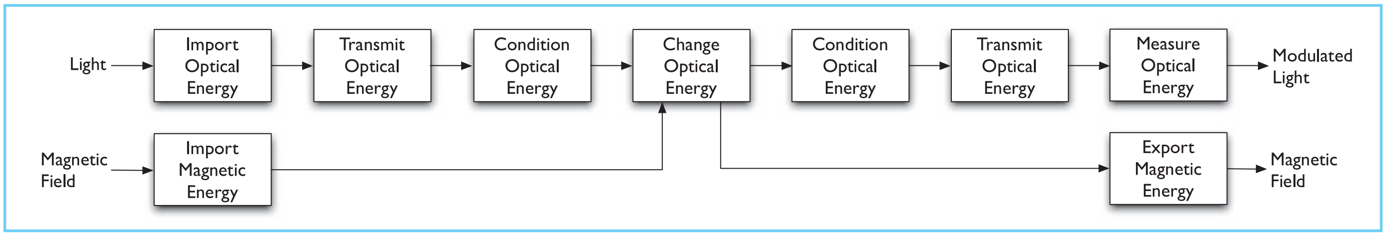


Table 3 Sample Query Results from Biology Corpus.

Corpus Location	Sentence
Paragraph 650 Sentence 1	The sense of taste, or gustation, in humans and other vertebrates depends on clusters of sensory cells called taste buds.
Paragraph 701 Sentence 10	Pit vipers such as rattlesnakes have pit organs, one just in front of each eye, that use highly sensitive heat detectors and a simple pinhole camera arrangement to sense and locate infrared radiation.
Paragraph 706 Sentence 3	Some fish can sense electric fields.
Paragraph 1108 Sentence 5	Bats use echolocation, pit vipers sense infrared radiation from the warm bodies of their prey, and certain fishes detect electric fields created in the water by their prey.
Paragraph 1439 Sentence 3	Pigeons are able to home as well on overcast days as on clear days, but this ability is severely impaired if small magnets are attached to their heads-evidence that the birds use a magnetic sense.
Paragraph 1439 Sentence 4	**Cells have been found in birds that contain small particles of the magnetic mineral magnetite, but the neurophysiology of the magnetic sense is largely unknown.**

within the system and allows the designer to query all possible forms of energy.

4.3. Query

An automated information-retrieval method is used for identifying search results relating to engineering function from any non-engineering domain corpus (e.g., biology, psychology) [38]. In this application, the black-box function of "sense magnetic energy" is the verb-noun pair that is used to query the biology corpus. Sample results are shown in Table 3. Of the 233 results, only three refer to magnetically-related topics. The magnetic sense of birds, Paragraph 1439 Sentence 4, is chosen for continued development. If no results were found then searching using the verb-noun pairs of the functional model that relate to the key sensor elements that are being re-designed, such as change optical energy, would be next action.

All other verb-noun pairs are used to query the engineering corpus for alternatives to complete the possible list of components for the design.

Figure 4 Magnetoreception System in a Homing Pigeon [42].

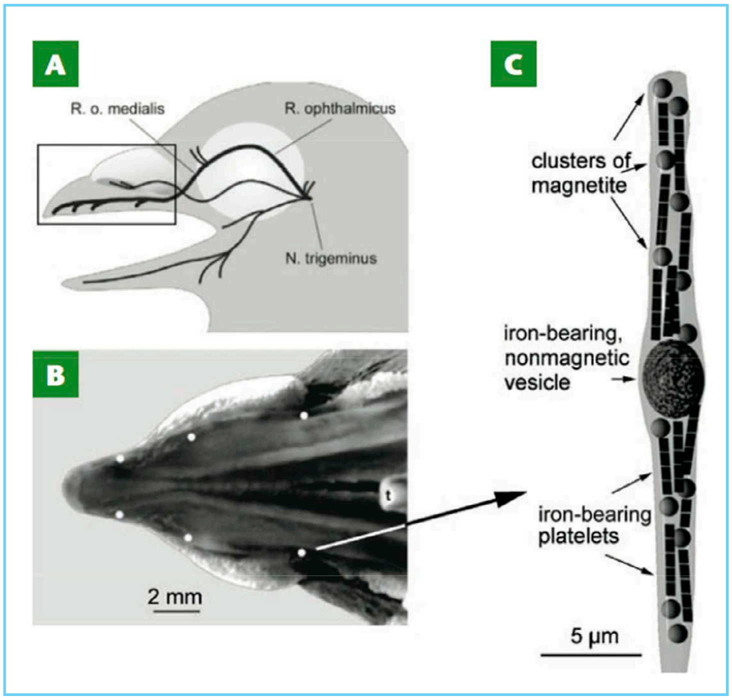
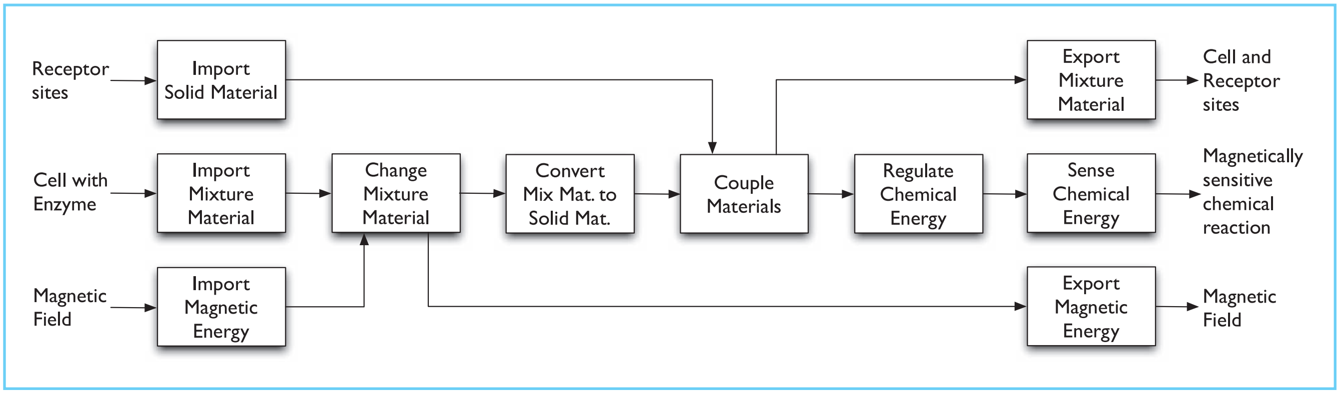


Figure 5 Biological Functional Model of Magneto-Optic Effects.



4.4. Make Connections

Searching journal databases for "magnetic sense" and "magnetite + birds" reveals that magnetoreception by biological systems is well established. In particular, birds have the ability to navigate using the earth's magnetic field. While the exact mechanism is still in question, the biological systems seem to depend on magnetite, an iron oxide crystal that aligns with magnetic north like a tiny compass needle [39, 40]. Research suggests that cells in a bird's beak contain magnetite and that these cells may serve as receptors that send directional information to the brain. Functionally, the magnetite-based magnetoreceptor cells measure magnetic field intensity and direction. The information establishes a magnetic map that is used for navigation. Birds measure magnetic field inclination through a light-dependent magnetoreception system within the eye [41].

To better understand the fundamental principles of how the magnetically-sensitive receptor cells convert an external stimulus (e.g., magnetic field) into an internal chemical signal that can be transmitted to, and processed by, the brain, a biological functional model was created as shown in Figure 5. With this understanding, connections can be made back to engineering for conceptualization of the OCT re-design. Magneto-optical effects have been investigated for magnetite as nanoparticles [43]. Also, magnetically-induced scatter has been shown [44].

The OCT re-design need not directly mimic the mechanism in birds; the identification of magnetite in biological systems is sufficient to inspire a novel approach. An engineering alternative of modifying light amplitude in an optical fiber rather than modifying light polarization can potentially be accomplished with magnetite. Consider evanescent-wave sensor structures [45], which is a common form of fiber optic chemical and biosensors. The optical fiber cladding is removed and is replaced with a gel, polymer, or thin film comprised of an immobilized material as shown in Figure 6. Magnetite as a magnetically-sensitive scattering or absorbing material can potentially attenuate the guided wave within the optical fiber.

Figure 6 Structure of an Evanescent-Wave Sensor with Magnetite.

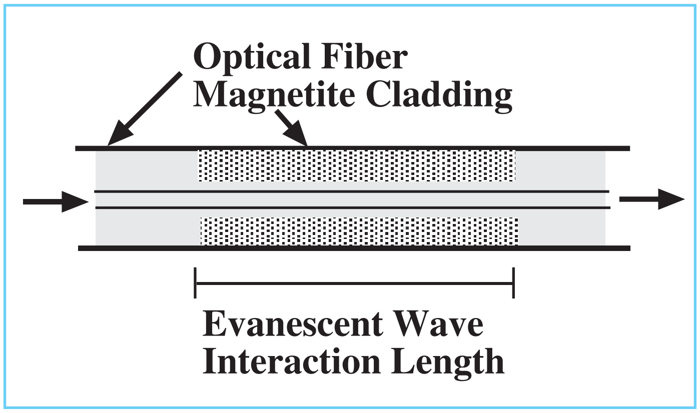
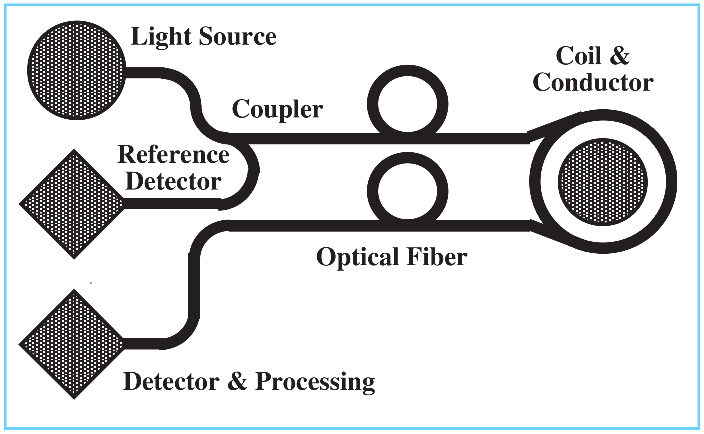


Figure 7 OCT Based on the Evanescent-Wave Concept.



4.5. Concept Generation

The re-design concept of the OCT is shown in Figure 7. The sensor head incorporates magnetite as in Figure 5 and surrounds the current-carrying wire. Amplitude-modulation of the light signal is based on Ampere's law as in the traditional OCT, but the re-design avoids sensitivities due to temperature, wavelength, and vibration that are present with a Faraday-effect approach. The simple instrumentation consists of a laser diode light source and a detector. A reference detector is added to track any variation in the light input from the source. Note that polarization control is no longer required, e.g. no need for polarization-maintaining optical fiber.

The concept is now ready for engineering development and specification. Research questions include what are the details of the magneto-optic response, how is magnetite best fabricated as an evanescent-wave coating, and what is the best wavelength to use with magnetite? Also, development will need to address the strength of the attenuation. While a single turn of optical fiber for the sensor head will probably produce a very small attenuation, multiple turns are possible. And, other sensor head arrangements can be explored which could enhance attenuation such as fiber loop ring-down spectroscopy.

5. Conclusions and Future Work

Sensors are an integral part of many engineered products, systems, and manufacturing processes as they provide feedback, monitoring, safety, and other benefits. This work addresses current sensing. Conventional current transducer technologies are limited and a bio-inspired re-design is identified that is based on magnetically-sensitive effects found within birds. Although the biological functional model is not identical to conventional CT and OCT functional models, the identified engineering analog is functionally similar and the bio-inspired design has the potential for enhanced performance. With the re-design concept, the feasibility of the proposed sensor system can be investigated with the appropriate expertise in materials, nanotechnology, and instrumentation.

Utilizing function-based engineering design methodologies, many opportunities arise for bio-inspired design. The biomimetic design method has shown to facilitate the conceptualization of bio-inspired technologies. Biological functional models need not be identical to the target engineering functional model; the identified engineering analog need only be functionally similar. Functional models allow for the identification of parallels between biological and engineering domains assisting with the inclusion of nature's elegance in engineering designs. Creativity in engineering design using the presented method is not limited to sensor design, and could be applied to other engineering problems further enabling collaboration and discovery between the engineering and biology communities.

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Dinosaurs Make Light Work—From the Engineering Problem to an Innovative Lightweight Product

by Hans-Joachim Weber and Martin Weber

In recent years there has been a trend within all areas of engineering to develop machines and systems which are more sustainable and to operate them in a sustainable way. How sustainability is defined is not always consistent, but most definitions are about minimizing resources in one way or another. One of the main resources is energy, the consumption of which should be reduced. This, of course, includes minimizing the emission of greenhouse gases.

There are several ways to minimize resources consumed. One possibility is to optimize processes, so as to increase efficiency. This has yielded some major improvement, especially with the use of numerical simulations.

Another, very effective, way is to utilize light weight construction (see fig. 1). On one hand, light weight might mean that less material is used. This has a number of consequences. Less material results in less energy being used when manufacturing and transporting semi-finished products. On the other hand, a smaller mass can result in smaller inertial forces and, hence, a lower energy consumption during motion. In addition, smaller inertial forces result in a higher precision of motion. Light weight construction is, thus, a goal which is pursued in many areas of development.

It is common to achieve light weight construction by using lightweight materials. This, however, while allowing for reducing energy consumption during operation, often leads to an increased energy demand during production (e.g. aluminum, magnesium) which reduces overall sustainability.

A different approach

When designing to increase sustainability and resource efficiency, one quickly hits upon an area of our environment which has already been addressing these issues for a long time: nature. Animals and plants have been forced for millions of years to strive on a limited supply of resources. This may be food, construction materials or energy. Over the course of evolution, organisms developed strategies to utilize these resources as efficient as possible in order to gain an advantage in the struggle for survival.

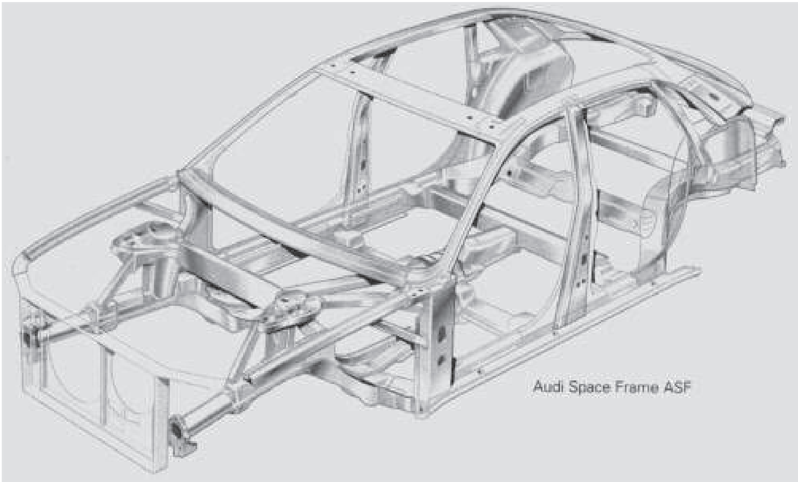

Fig. 1 Audi space frame [1]

Nature is subject to the same natural laws as engineering. This means that, in principle, solutions found by nature may be used as approaches to solve engineering problems. The science which deals with the transfer from nature to engineering is called biomimetics (also bionics, biomimicry). The goal of biomimetics is not to copy solutions directly, but rather to understand the underlying principle and to transfer that into the engineering context.

Solutions found by way of biomimetics offer the advantage that they have already been subject to rigorous tests by natural selection. They do not contradict the laws of physics, meet the requirement of being economical and already offer features which match the working principles involved. Another major advantage of the solutions arrived at is that they are independent of the current limits of scientific knowledge. This means that it is possible to find solutions which go beyond the current state of the art in engineering.

When looking at the range of resource efficient solutions from nature, it is apparent that lightweight construction plays a major role.

Generally speaking, natural systems tend to first exploit structures which permit the reduction of material by reducing inner stresses. In addition, lighter materials are also employed. Nature does, however, not resort to expensive (i.e. resource intensive) special materials, but rather arranges conventional materials in such a way within a composite structure as to withstand the stresses with as little material as possible [2,3,4]. Unfortunately, this principle can usually either not be adopted using conventional manufacturing techniques or adopting this principle is prohibitively expensive. As 3D printing evolves, it might be possible, in the near future, to also construct materials based on the example of nature.

Finding biomimetic solutions

This section describes how to arrive at a biologically inspired solution for a given engineering problem. The approach is exemplified using the lightweight design of a bucket excavator boom (Fig. 2 and 3).

Why is light weight design of importance for an excavator? As previously mentioned, lightweight design results in a reduction of material, reduced energy

Fig. 2 Type of excavator used for the study [5]

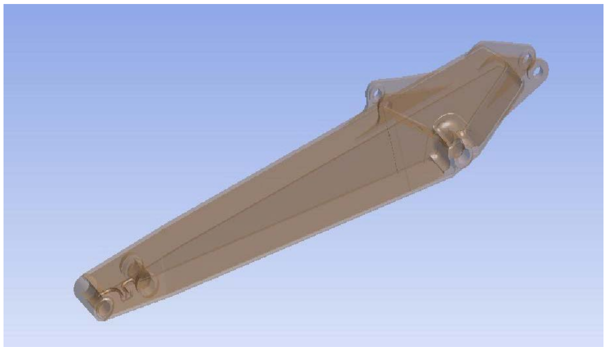

Fig. 3 CAD drawing of the bucket excavator boom

consumption when moving, possibly a quicker motion and a more accurate positioning. In addition, reduced weight on the load bearing side also reduces the required counterweight, so that further material savings can be achieved.

When searching for biomimetic solutions to engineering problems, it is easy to get overwhelmed by the sheer number of potential examples. This can quickly lead to development costs which only large compa-nies can afford. In order to arrive at suitable solutions in the tight time and budget frames of present day engineering development, it is, thus, necessary, to reduce the scope of search to something more man-ageable. Using a methodical design approach as advocated by Pahl / Beitz [6], can greatly help towards this end.

The idea behind the approach of Pahl / Beitz is to not try and devise the concept of a machine or compo-nent in one hit, but to, rather, break down the overall design problem into smaller sub-problems. These sub-problems, which are equivalent to the functions the system is required to fulfill, are more manageable. It is possible for each sub-problem to either reuse a solution which already exists or to devise a new one. Once a solution for each sub-problem has been found, the system solution can be arrived at by integrating the partial solutions.

In short, methodical design can then be described as a way to explore the design problem and to guide the attention of the designers to the key issues. And it is this exploration and guidance that makes the approach so suitable for the implementation of biomimetics into the design process. The reason is, that the components used in engineering rarely have a counterpart in biological systems; but the functions do. There are, for instance, no tires in nature one can turn to for inspiration, but there are numerous ways to increase grip (which led to the design of Continental's bionic tires [7]). And so, the output of the problem definition phase, that already is an integral part of Pahl / Beitz, serves as the input for the biomimetic search.

This approach was implemented in the following way in this project. The requirements for the excavator boom were used to find a number of main functions which the boom needs to fulfill. These functions were then used to define a scope of search. Since it is not possible to search for a scope, it was necessary to choose a number of key words that yielded solutions within the scope of search.

For this example the following main functions were identified:

- Receive forces
- Transmit forces
- Prevent deformation
- Enable motion

Based on these functions the scope of search was chosen to be "receive and transmit forces". The following key words were used in the excavator boom design: Receive force, transmit force, structures, lightweight design, and lightweight structures.

Every key word yielded a number of examples which were evaluated for their applicability to the current problem. If the solution proved relevant, the concept of the solution was abstracted and an engineering adaptation in the form of a concept was developed.

The multitude of solutions led to four key concepts which might be adapted to a new boom design. These four possibilities are presented below.

Honeycombs

One example for a lightweight structure is found very frequently and is already employed in engineering. This is the honeycomb structure.

The weight of bee and wasp nests is low because the structure is made of hexagons. This results in a lightweight, yet very durable structure.

Honeycombs can be adapted for use in excavator booms in more than one way. One possibility is to use honeycomb plates as a partition panel (fig. 4). This allows for the outer panels to be thinner and to, thus, reduce the overall use of material. Another possibility is to use honeycomb structures on the outside panels of the boom. Two variants were designed. The first one used honeycombs for the side panels (fig.5), the second one used them for the top and bottom panels (fig. 6). Computer simulations yielded the following weight reductions for the three cases:

Honeycomb A: 20%
Honeycomb B: 27%
Honeycomb C: 23%

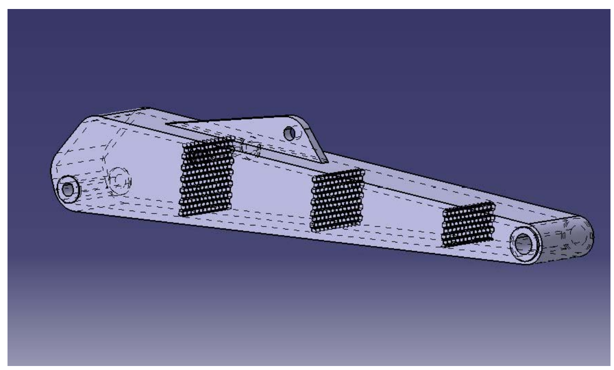

Fig. 4 Honeycomb plates as a partition panel, Honeycomb A

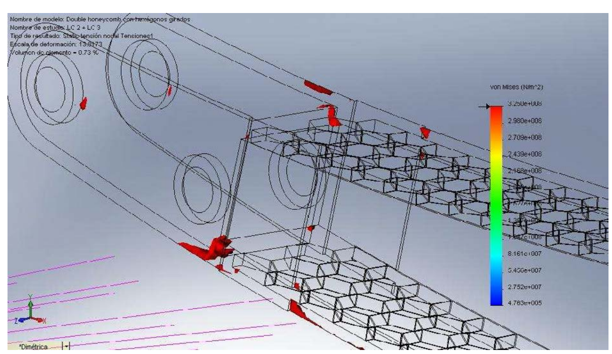

Fig. 5 Honeycomb structure as top and bottom panel, Honeycomb B

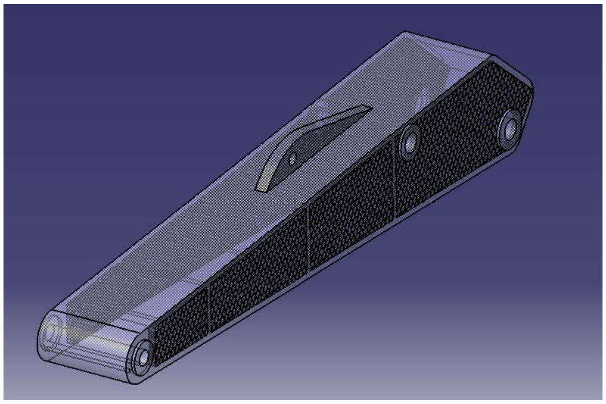

Fig. 6 Honeycomb structure as side panel, Honeycomb C

The higher weight reduction in example B can be attributed to the fact, that the upper and lower parts of the boom carry the highest stresses. Weight reductions are, thus, more noticeable.

Biological stiffening ribs

The honeycomb structure was also the inspiration for another concept. The outer contour of a network of combs form a structure with stiffening ribs, as it can also be seen, for instance, with palm leaves. This concept also has a high strength and stiffness (fig. 7).

Banana leaves

Another structure which provides inspiration for lightweight structures are stalks of plants. The stalk of a banana leaf (fig. 8) was chosen here as an example. As can be seen in fig. 9, there are ribs in the interior of the banana plant stalk. These ribs are tension structures ([2,8]) and, therefore, the stalks of the plants are very light.

To translate this structure into an engineering solution, several model beams with varying cross-sections were developed. These models were evaluated with respect to their load bearing capabilities and possible weight savings using a finite element (FE) analysis (fig 10). The analysis showed, however, that, for the same permissible deformations, no weight savings could be achieved. The second moment of area of the banana leaf structure is very low in comparison to a box section. This is because much of the material is arranged in the center of the structure. The increased flexibility of the stalk is not an error, but a feature, as it allows the banana plant to reduce the wind load by reducing the projected area as it swerves out of the wind. In order to reduce bending and to keep deformations within the acceptable limits, it is necessary to increase the cross-sectional area and, hence, no weight savings can be achieved.

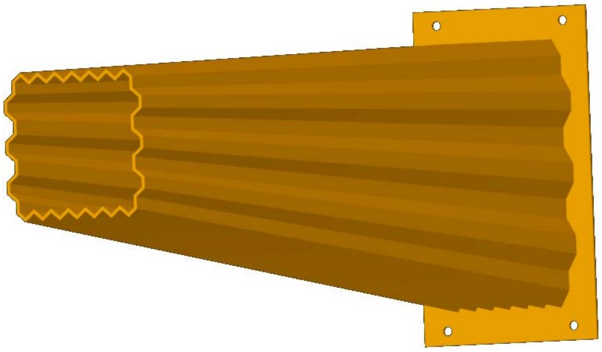

Fig. 7 CAD drawing of a beam with stiffening ribs structure

Fig. 8 Banana plant

Fig. 9 Cross-section of the stalk of a banana leaf

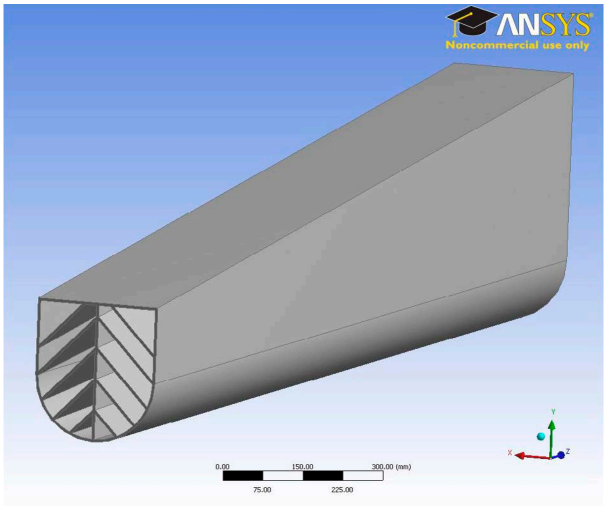

Fig. 10 FE-model of a beam with banana leaf cross-section

This example shows that not all examples from nature which on the surface seem to fulfill the desired outcome (in this case: weight reduction), are able to solve a specific engineering problem. What needs to be taken into account at all times are the constraints. As can be seen in this example, it is possible that the solution arrived at is useless for the specific problem under consideration if only one constraint is different between the natural and the technical situation. This is generally a sign that the biological solution was not completely understood.

Sauropods necks

As mentioned at the beginning of the article, one of the advantages of using biomimetics to find design concepts is that they may lie beyond the horizon of expectations of engineers. This means that a solution might be found which nobody would have expected. This is also the case when searching for lightweight structures. One of the solutions one expects to find is bird bones.

There is, however, another phenomenon which is worth noting. Birds possess a system of air sacs which, among other functions, also helps to stabilize their bodies. When probing further, it can be found that close relatives of birds, the dinosaurs, possessed a much more complex air sac system [9] (see fig. 11). New research revealed that this was employed to assist the load bearing capabilities of sauropods [10].

In order to use this knowledge for lightweight design, it is first necessary to understand the underlying principle.

Sauropods had a very distinctive body. They had extremely long necks and tails. Necks as long as 12m with massive, barrel-shaped bodies, and heads which were disproportionally small. In the course of their evolution, they acquired up to six new cervical vertebrae. In addition, the individual vertebrae got longer, sometimes reaching a length of 1m.

Special mechanisms were necessary for the sauropods to bear their extremely long necks. This was achieved by vertebral bodies with a special lightweight construction in combination with a bracing mechanism of ligaments, muscles, and tendons, as well as an air sac system, akin to that of present day birds. Pneumatic diverticula (inflated tissue blebs) formed a segmented air sac system along the cervical spine.

Computer tomographic examinations of the vertebral bodies showed that, depending on the location of the vertebra, up to 60% of the bone material had been replaced by pneumatic structures [13, 14, 15, 16, 17, 18]. The average thickness of the bone on the outer sections of the vertebral bodies examined was between 3 and 6mm whereas the thickness of partitioning bones between the pneumatic diverticula was as low as 1 to 2mm. The portion of the vertebra that was occupied by the cavity, and, thus, the reduction of weight, is directly proportional to the length of the neck and the body size of the sauropods. Further examinations using finite element analysis (FEA) revealed that the pneumatic cavities only occupied areas within the vertebra body that were almost free of stresses [19, 20, 21]. The bone material around the cavities, which acts like a framework, transmits the loads to the outer brace of ligaments, muscles, and tendons. This is how very strong, yet lightweight, vertebrae were possible.

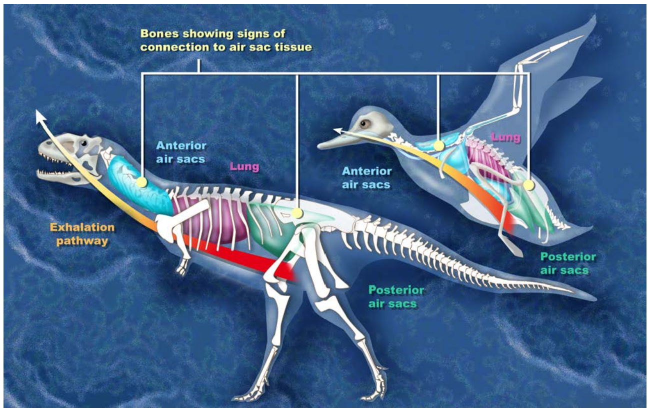

Fig. 11 Air sac system of dinosaurs and birds [11, 12]

Fossil bone finds showed that vertebral bodies of higher developed sauropods (neosauropods) had larger cavities. This indicates that the lightweight strategy must have been successful. In addition, it is possible to reconstruct the development of the air sac system from infant to full grown adult. For full grown animals almost 75% of the lateral bone material is replaced by interconnected, pneumatic cavities. The larger the animal, and, thus, the longer the neck, the more grew the lightweight structures of pneumatic diverticula [19, 20]. It is furthermore possible, that the air sacs were also used to dampen vibrations created while walking [14].

Transforming the Biological Principles into Technical Solutions

To explore this concept in more detail, a functional model was designed on the basis of cable ducts forming a hinged arch which modelled the flexibility of the dinosaur neck (see fig. 12). The supporting effect was modelled by hoses which were inserted. Several hose arrangements and further supporting structures were tested.

For the experiments one side of this assembly was fastened, so that the duct formed a cantilever, while

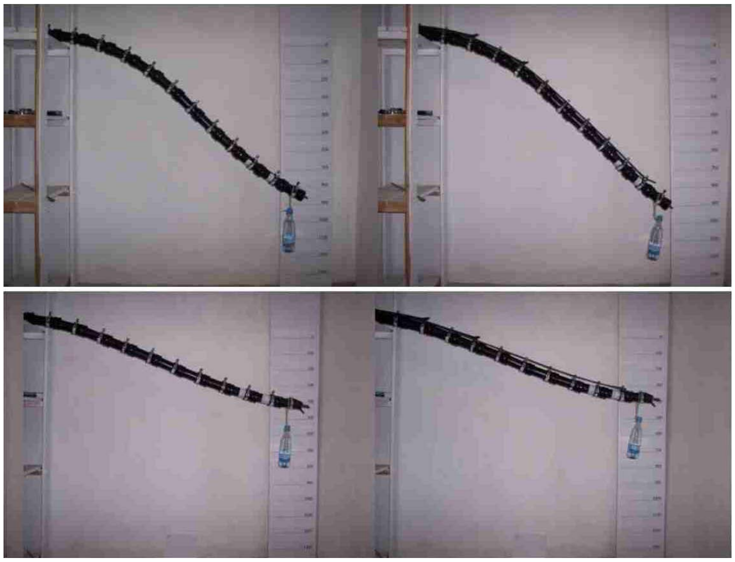

Fig. 13 Deflection of the model with load and with different internal pressures

the other end was loaded by some weight. This corresponds to the natural loading of the dinosaur neck. The deformation of the duct for various air pressures was then determined. The deflection can be read off the scale on the right hand side. Fig. 13 shows exemplary results of four test runs. As can be seen, an increase in pressure results in an increased support of the structure (i.e. in an increased second moment of area).

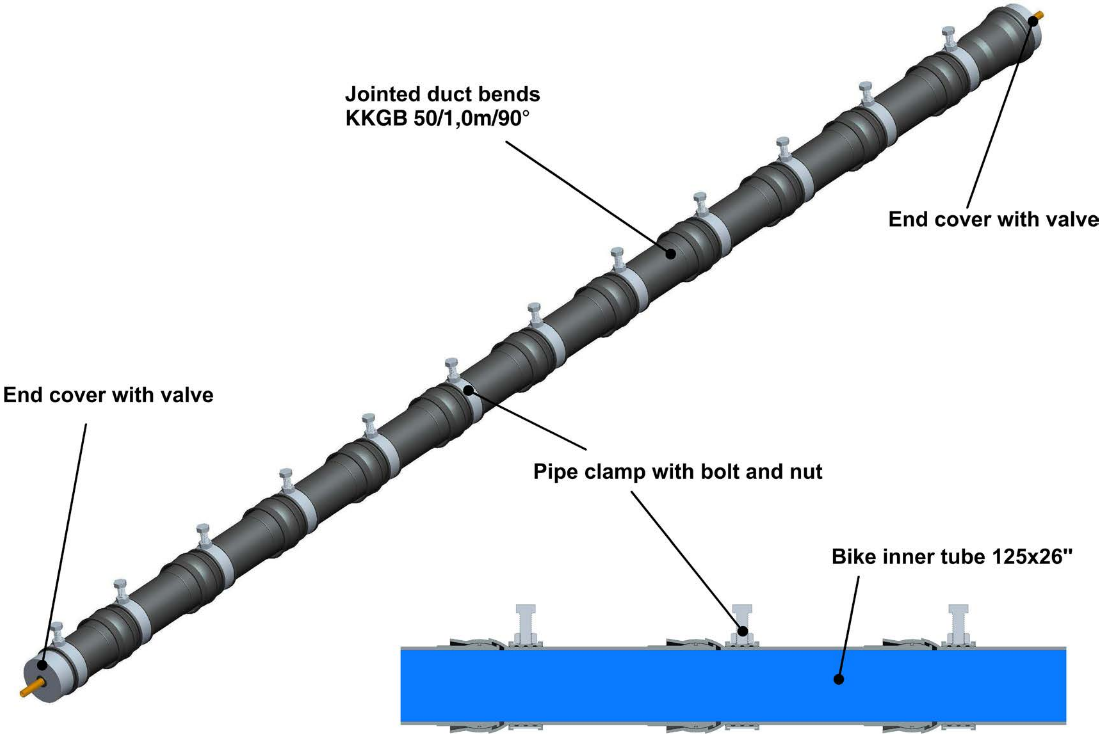

Fig. 12 Basic setup of the model

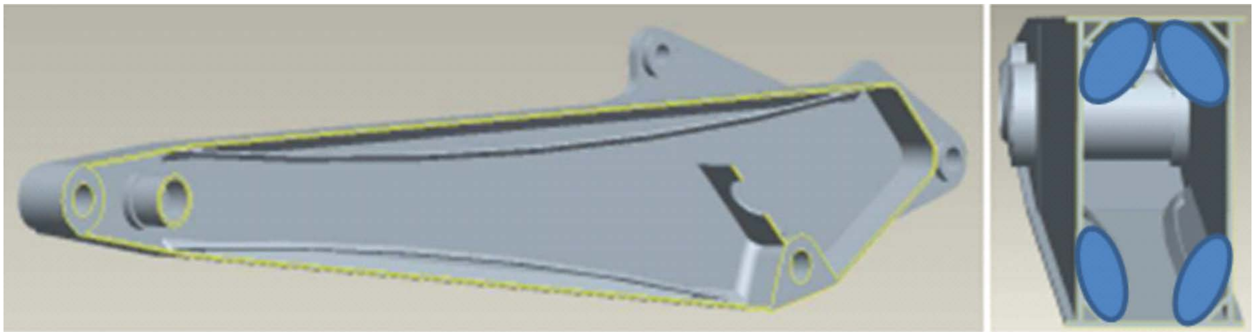

Fig. 14 CAD-model of an excavator boom with integrated air chambers

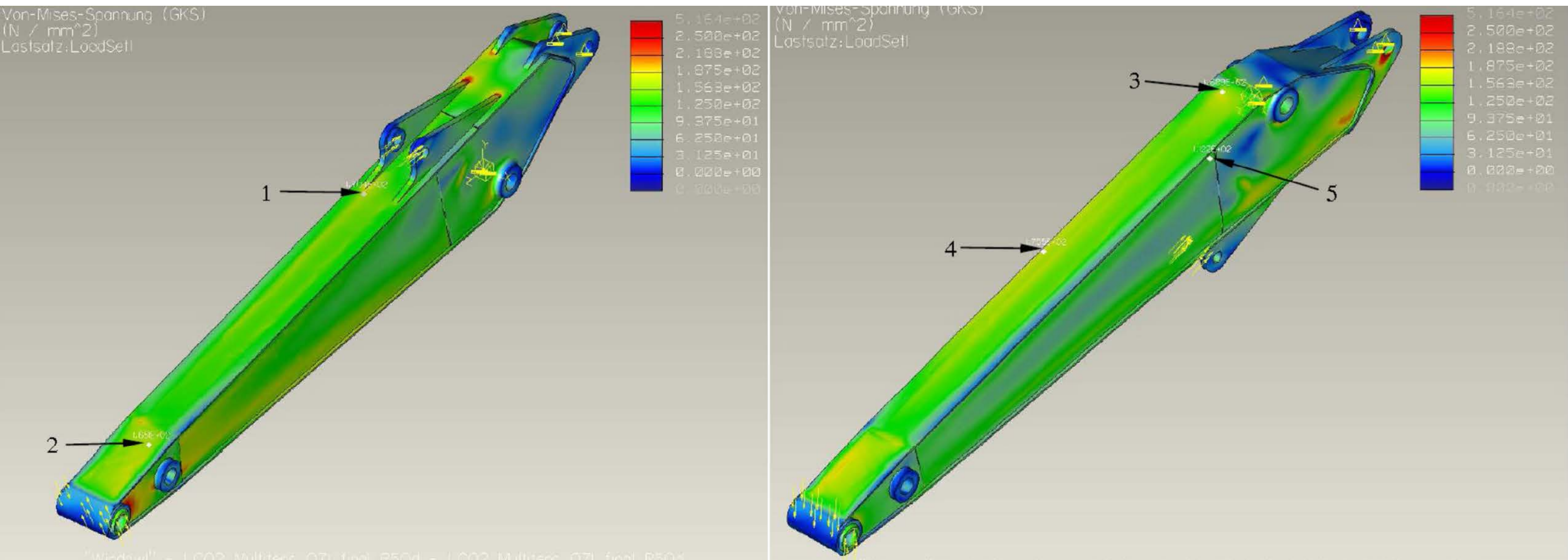

Fig. 15 The five locations chosen for the benchmarking exercise

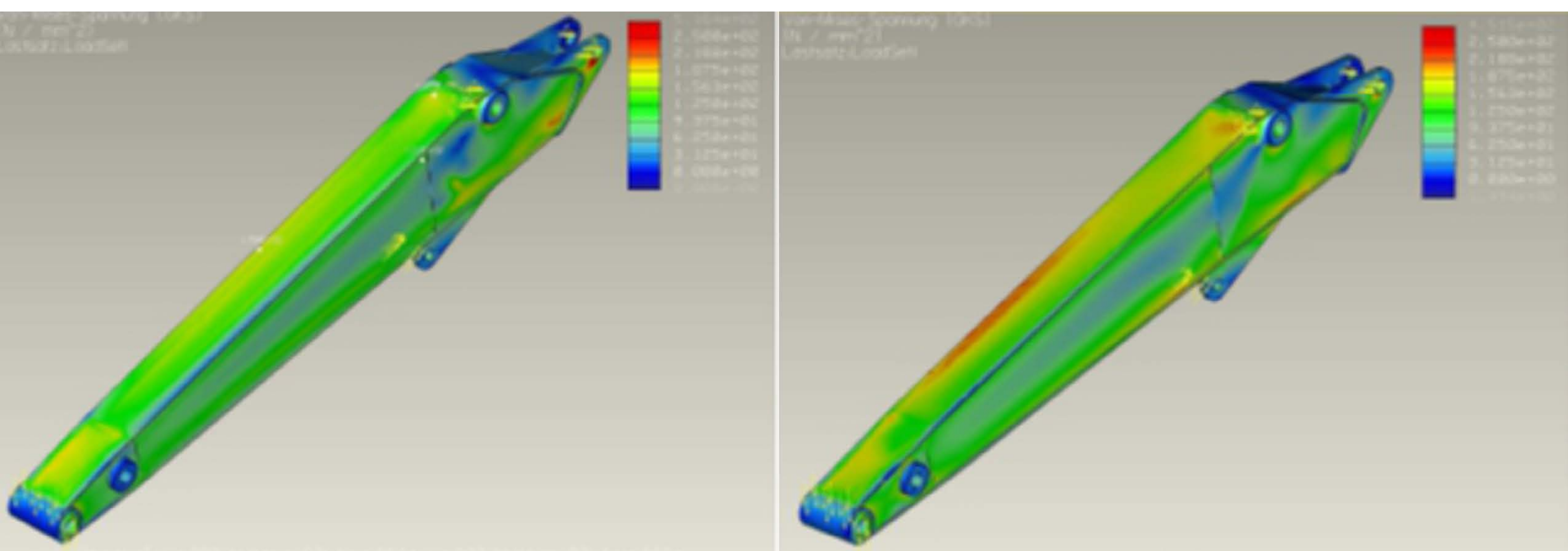

Fig. 16 FE-simulation of the loading of an excavator boom for load case LF02 with pneumatic support (left) and without modification (right)

Tab. 1 Stress at the five locations compared and maximum displacement of the excavator boom

Location	Not modified boom		Boom with pneumatic support	
	stress (N/mm²)	max. displacement (mm)	stress (N/mm²)	max. displacement (mm)
1	237,1		170,4 (-28.1%)	
2	178,1		165,1 (-7.3%)	
3	202	16,2	168,9 (-16.4%)	14,6
4	223,4		175,5 (-21.4%)	
5	182,8		112,2 (-38,6%)	

After establishing experimentally the effectiveness of supporting load bearing structures by pneumatic elements, this principle was now ready to be transferred to a technical solution. In principle, there are several ways in which a biological example can be transferred to an engineering system. On the one hand the overall design of the engineering system may be altered relatively little and only few aspects of the biological solution are applied. On the other hand the design of the technical system can be changed in more fundamental ways, which might also lead to a completely new concept. In the most extreme of cases it is possible that a completely new working principle is developed which leads to a more or less costly development process.

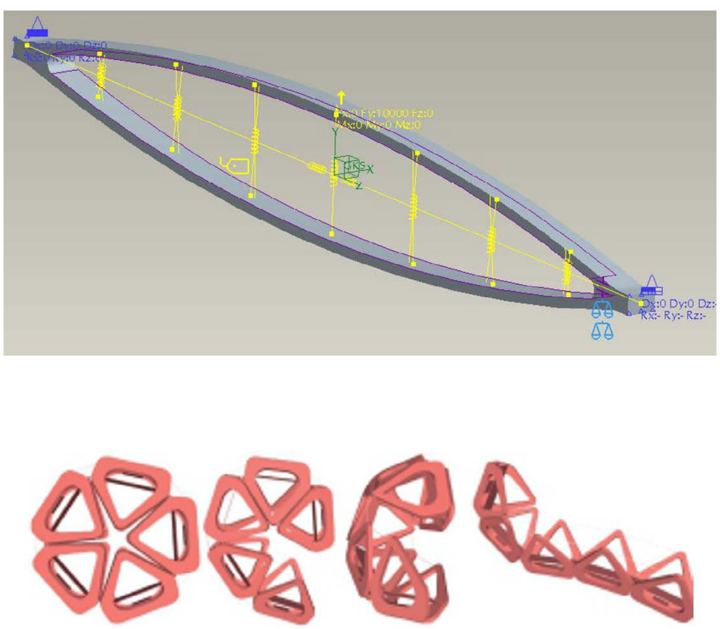

Fig. 17 Concept sketches of an excavator boom as elastic structure with pneumatic support (above) and of a segmented excavator boom (below, Project Rollasselbrücke, Department of Architecture, University of applied sciences HTW, Saarbrucken, Germany)

For this paper, the objective was to stick as closely as possible to the original working principle and, yet, achieve significant weight savings. To achieve this, air chambers were integrated into the existing design (fig. 14). The effectiveness of this approach was investigated by FE analyses. This was done using the load cases specified in relevant engineering standards [22] and the results were benchmarked against the original design. Fig 15 shows the 5 locations which were chosen for the benchmark.

Tab. 1 and fig. 16 show, for instance, the result for load case LF02 from source [22]. It can be seen that the maximum stresses in the design without pneumatic support (Fig 17 right image) are significantly higher. Depending on the load case under consideration, the stress reduction which can be achieved varies between 16 and 23%. The simulations have not been verified by tests using real components.

As mentioned before, it was the aim to change the conventional design principle as little as possible. Challenging the underlying principle on a deeper level, however, leads to the possibility of arriving at new working principles, as they can be seen in fig. 17.

Conclusion

The examples presented in this paper show that a biomimetic search enables the designer to tap into the pool of solutions which nature developed over the course of evolution.

This, however, only works if the development goal, and, thus, the direction of the biomimetic search, has been carved out by using a clear, methodical approach. On the other hand, it is to be ensured that the constraints of the engineering situation are comparable to those under which potential biological solutions operate in. Otherwise, the biological solutions will not be able to fulfil the requirements of the engineering problem.

Since nature has often taken paths which are different from those of engineers, it is possible to arrive at solutions which are outside the engineering focus in conventional development projects. This is exemplified very well with the lightweight design on the basis of sauropods necks. The advantage of this solution is also that it is possible to adjust the deformability of the structure by varying the internal pressure. For certain applications this might form the basis of a radically different design principle for load bearing, cantilevered structures.

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Author Biographies

Prof. Dr.-Ing. Hans-Joachim Weber studied mechanical engineering at the University of Karlsruhe/Germany. He worked for about 15 Years in the R&D department of several companies of the mechanical engineering industry. After that he became a professor at the University of Applied Sciences (HTW) in Saarbrucken/Germany. His special field is the integration of biomemetic methods in the development process of mechanical machinery and he is director of the Institute of Product Development and Optimisation (InPEO) at the University of Applied Sciences (HTW) in Saarbrucken/Germany.

Martin Weber MSc studied mechanical engineering at the University of Brighton/UK and design of rotating machines at Cranfield University/UK. For his bachelor dissertation he looked at using biomimetics for the optimization of load bearing structres.

He worked on several biomimetic projects for the Institute of Product Development and Optimisation (InPEO) at the University of Applied Sciences (HTW) in Saarbrucken/Germany as well as development engineer in the wind and automotive industries. He is working as a development engineer at Continental Engineering Services (CES) in Nuremberg/Germany.

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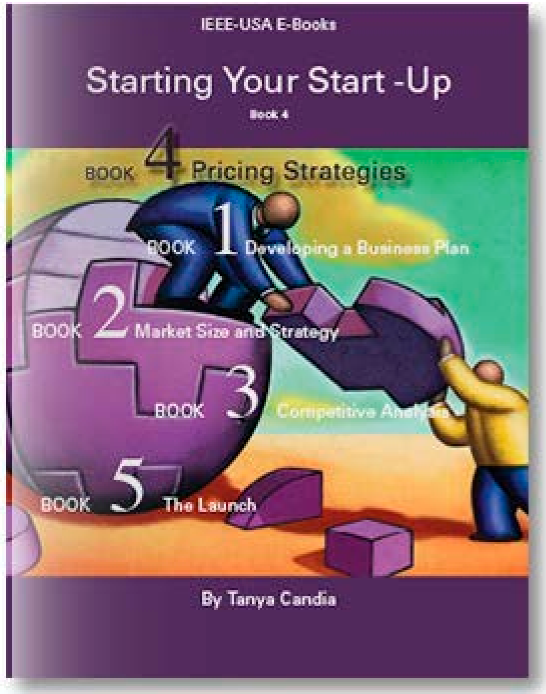

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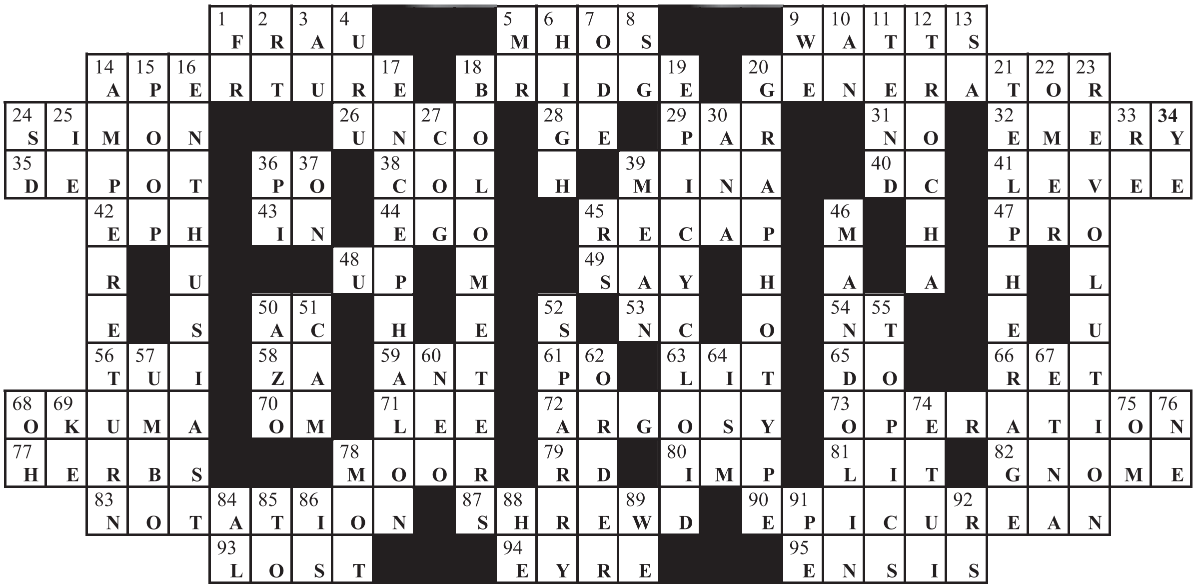
The free E-Book for April will be "Engineers Working with Teachers, A Handbook for Bringing the Excitement of Engineering, Science, Technology, Invention, and Creativity into the Classroom" available from April 1–May 15 with code APRFREE16.

The October 2015 issue reprinted the H•K•N crossword puzzle that appeared in the March 1925 issue of THE BRIDGE. The solution to this puzzle by Paul W. Kiesling, I '24 was given in the May 1925 issue and is shown below. Four correct solutions were received in 1925; they were

W. R. Beach, Z '21; M. S. Mason, A '11; H. M. Piety, D '23; and W. C. Pomeroy, M '18.

Alexander McClanahan, Gamma Theta 2015, submitted a nearly complete solution. Congratulations Alexander! A blank copy of the crossword with clues is available in the October 2015 issue and at this link: http://bit.ly/IEEEHKNCrosswordPuzzle



Clues and Solution

Note that the answers and clues reflect the time period for language, geography, etc.

HORIZONTAL

1. A married woman (German). **FRAU**
5. Proposed unit of Conductance (pl.). **MHOS**
9. Unit of electric power (pl.). **WATTS**
14. Gap. **APERTURE**
18. The official publication of Eta Kappa Nu. **BRIDGE**
20. Source of an electric current. **GENERATOR**
24. One of the twelve apostles. **SIMON**
26. Scottish word for uncouth. **UNCO**
28. Trade Mark of large electrical manufacturing concern. **GE (GENERAL ELECTRIC)**
29. An accepted standard with which to compare variations. **PAR**
31. A negation. **NO**
32. Abrasive. **EMERY**
35. A warehouse or structure. **DEPOT**
36. River in Italy. **PO**
38. A depression between two mountains. **COL**
39. Ancient weight of money, of varying value. **MINA**
40. Direct current (abbr.). **DC**
41. An embankment. **LEVEE**
42. Book of the New Testament (abbr.). **EPH (EPHESIANS)**
43. Prefix meaning: Into or on. **IN**
44. Personality. **EGO**
45. Review briefly. **RECAP**
47. In behalf of. **PRO**
48. Aloft. **UP**
49. Recite. **SAY**
50. Alternating current. **AC**
53. State bordering on Georgia (abbr.) **NC (NORTH CAROLINA)**
54. New Testament (abbr.) **NT**
56. Personal pronoun "thou, you" (Latin). **TUI**
58. Very (scientific prefix). **ZA**
59. Insect. **ANT**
61. Government department (abbr.) **PO**
63. Past of light. **LIT**
65. Musical note. **DO**
66. To steep or soak, as flax. **RET**

68. Japanese statesman and financier. **OKUMA**
70. The sacred sound and spiritual icon in Indian religions. **OM**
71. Sheltered side. **LEE**
72. A large richly laden ship, as formerly of Ragusa. **ARGOSY**
73. A mode of action. **OPERATION**
77. A plant that dies after flowering. (pl.) **HERBS**
78. To fasten. **MOOR**
79. Read (abbr.) **RD**
80. Evil spirit. **IMP**
81. Same as 63 horizontal. **LIT**
82. A dwarf. **GNOME**
83. The process of designating by figures. **NOTATION**
87. Sagacious. **SHREWD**
90. Pertaining to the doctrine that pleasure is the chief good. **EPICUREAN**
93. Wasted. **LOST**
94. A circuit or journey (archaic). **EYRE**
95. Sword. (Latin). **ENSIS**

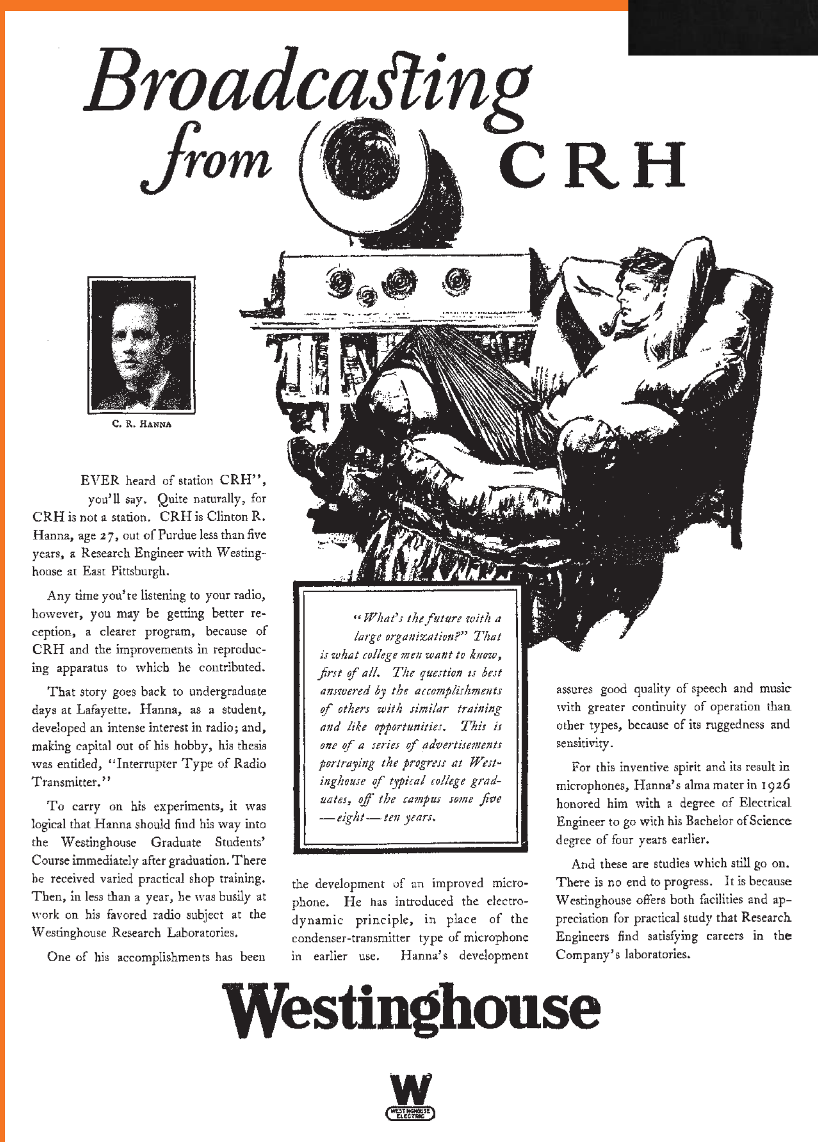
VERTICAL

1. A French silver coin (in 1925) (abbr.). **FR (FRANC)**
2. Right (abbr.). **RT**
3. Precious element (symbol). **AU**
4. Country of South America (abbr.). **URU (URUGUAY)**
5. Title of address (abbr.). **MR**
6. Lofty. **HIGH**
7. A brief poem. **ODE**
8. Relative weight (abbr.). **SG (specific gravity)**
9. Personal pronoun. **WE**
10. Indefinite article. **AN**
11. To move in a certain direction. **TEND**
12. A path or road. **TROCHA (SPANISH)**
13. A continent (abbr.). **SA (SOUTH AMERICA)**
14. Equals $\frac{\text{Hx1x10}}{\text{4 pi}}$ (singular). **AMPERETURN**
15. The stern of a vessel. **POOP**
16. Zealot. **ENTHUSIAST**
17. The brain. **ENCEPHALON**
18. An instrument made by inserting in the moving coil of a sensitive D'Arsonval galvanometer, a bismuth-antimony thermo-couple, so that one-hundred-millionth of a degree centigrade can be measured (pl.). **BOLOMETERS**
19. A curve. **EPICYCLOID**
20. A process for producing engravings. **GRAPHOTYPE**
21. Automatic aerial transportation by electricity. **TELPHERAGE**
22. A Hebrew measure of 5.1 pints. **OMER**
23. A round of successive changes. **REVOLUTION**
24. A state bordering on Iowa (abbr.). **SD (SOUTH DAKOTA)**
25. For example. **IE**
27. A tenon. **COG**
30. Literary bits. **ANA**
33. Musical note. **RE**
34. Nominative plural of the personal pronoun of the second person. **YE**
36. Geometrical ratio. **PI**
37. Condition of adherence. **ON**
39. Intermediate as to time. **MEAN**
45. Coin of British India (in 1925) (abbr.). **RS (RUPEES)**
46. Musical Instrument. **MANDOLIN**
50. Containing nitrogen. **AZO**
51. Device to convert rotary into reciprocating motion. **CAM**
52. Of, abounding in, or like spar. **SPARRY**
55. Subjects of discussion. **TOPICS**
57. Boss or knob. **UMBO**
60. New (Comb. form). **NEO**
62. Degree of algebraic expression. **ORDER**
64. A doctrine or system: Satirically. **ISM**
67. A small vessel for boiling water. **ETNA**
68. An exclamation. **OH**
69. Energy depending on motion (abbr.). **KE**
74. A case for carrying small articles. **ETUI**
75. Same as 70 horizontal. **OM**
76. New England (abbr). **NE**
78. A bugle note. **MOT**
84. An eastern Governor (nickname). **AL**
85. Toward. **TO**
86. Form of verb "to be". **IS**
88. Personal pronoun. **HE**
89. Personal pronoun. **WE**
91. Presiding Elder (abbr.). **PE**
92. Same as 45 vertical. **RS**

Westinghouse Engineer C. R. Hanna

The company Westinghouse has been associated with many aspects of electrical engineering history, and it has employed many Eta Kappa Nu members. The advertisement shown below appeared on the back cover of the November 1926 issue of THE BRIDGE as well as other publications of the time. Eta Kappa Nu member Clinton R. Hanna is featured a mere four years after his graduation from Purdue University with a B.S. in electrical engineering. He started as a research engineer in 1922 and retired as associate director of research for Westinghouse in 1960. His work produced more that 100 patents related to such diverse topics as audio technology, sound motion pictures, automated control, and aircraft automatic pilot systems. Among his awards were the 1955 Lamme Medal from the American Institute of Electrical Engineers and a 1942 Presidential Citation from Franklin D. Roosevelt. The former award recognized the body of his work while the Presidential Citation recognized Hanna's invention of a gyroscopic stabilizer to aid in the accuracy of tank guns. A contemporary article that describes this war contribution is (available at http://hdl.handle.net/1811/36137)

F. D. Roosevelt presents Presidential Citations in 1945 including C. R. Hanna (sixth from left). Library of Congress Photograph.



Westinghouse Advertisement, THE BRIDGE, November 1926.

Will Summers, "Stabilized Guns for Yanks Tanks," Ohio State Engineer, 28(4), pages 10–11, 23, March, 1945.

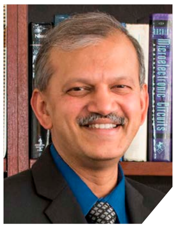
IEEE-HKN Board of Governors Election Results

IEEE-HKN's annual election for the 2016 IEEE-HKN Board of Governors was held in the autumn of 2015, and the Tellers Committee has confirmed the election of the following new Board Members:

- 2016 IEEE-HKN President-Elect / 2017 IEEE-HKN President: Timothy Kurzweg
- 2016 IEEE-HKN-BOG Student Representative/ Governor: Leann Krieger
- 2016–2018 IEEE-HKN-BOG Member-at-Large/ Governor: Ed Rezek
- 2016–2018 IEEE-HKN-BOG Region 3-4 Governor: Ronald Jensen

These representatives will join the following as the 2016 IEEE-HKN Board of Governors:

President - S. K. Ramesh
Past President – Evelyn Hirt
Governor Regions 1&2 – Kenneth R. Laker
Governor Regions 7-10 – Mo El-Hawary
Governor-At-Large – Nita Patel
Governor Regions 5&6 – Gordon Day
MGA Governor-At-Large – Sampathkumar Veeraraghavan



S.K. Ramesh has also been elected as the 2016 Vice President of Educational Activities. Congratulations Ramesh!

Meet the new members of the IEEE-HKN Board of Governors:

Timothy Kurzweg (President Elect)—Epsilon Chapter

Dr. Timothy Kurzweg is an Associate Professor in Electrical and Computer Engineering Department at Drexel University, Philadelphia, PA. He obtained his B.S. degree from Penn State University and M.S. and Ph.D. from the University of Pittsburgh. He joined Drexel in 2002, and was appointed the Associate Department Head of Undergraduate Affairs in 2010, as well as the Director of the Bachelor of Science in Engineering Program in 2010. He is the recipient of the 2011 C. Holmes MacDonald Outstanding Teacher Award from IEEE-HKN, and the Drexel University Christian R. and Mary F. Lindback Award for Distinguished Teaching in 2009. In 2009, he co-founded MetaTenna LLC, a startup that spun out of funded research at Drexel in transparent, flexible antennas. His technical interests are in the area of micro-optical systems for biological sensing, communication, and imaging.

Leann Krieger (Student Representative/Governor)—Gamma Theta Chapter

Leann Krieger is a Senior in Electrical Engineering with an emphasis in Power and Energy at Missouri University of Science and Technology (Missouri S&T). She is from St. Louis, MO, but she currently resides in the Solar Village on the Missouri S&T campus. She served as the President of the Missouri S&T IEEE Student Branch in both Spring and Fall 2015. Leann was the Director of Public Relations for the Missouri S&T Solar House Design Team, which designs and builds net-zero solar-powered homes for a design competition sponsored by the U.S. Department of Energy, and after her executive position has stayed active on the Electrical Subgroup of this student design team. She has held the position of Vice President for the Missouri S&T Section of the Society of Women Engineers.

Edward Rezek (Member at Large/ Governor)—Delta Zeta Chapter

Edward A. Rezek received a BS degree in Electrical Engineering and an AB degree in Physics from Washington University in St. Louis, MO in 1976. He received his MS and PhD degrees in Electrical Engineering from the University of Illinois, Urbana-Champaign, IL in 1977 and 1980. He is a member of Tau Beta Pi, Eta Kappa Nu, Omicron Delta Kappa, and Sigma Xi. He has been a member of Northrop Grumman Space Technology (formerly TRW Space & Electronics Group), an entity specializing in electronics development for

U.S. Government and commercial applications, since 1980. His work experience has ranged from basic research and development to manufacturing, and has covered the spectrum from advanced technology development for U.S. Government space applications to manufacturing low cost components for commercial applications. He has received 19 patents and has >50 publications in refereed journals. He is the 1993 recipient of the TRW Chairman's Award for Innovation and the 2006 recipient of the Northrop Grumman Distinguished Innovator Award. Ed is an IEEE Fellow.

Ronald Jensen (Region 3-4 Governor)—Nu Chapter

Ron Jensen served as Treasurer for the IEEE-HKN Board of Governors in 2015, and will also continue to serve as Treasurer in 2016. Ron recently retired as Chief Engineering Manager at IBM, managing a team of people across three countries covering IBM server hardware and software. During his career at IBM, he held positions in semiconductor process, chip development, and semiconductor applications, followed by system design, systems architecture and project management. He led in the development of IBM families of computers and servers. He was inducted into the Nu Chapter of IEEE-HKN at Iowa State University in 1972. He received the BSEE from Iowa State University and MSEE from Syracuse University and completed Ph. D courses from the University of Minnesota. In addition to his activities with IEEE-HKN, Jensen is a member of the IEEE Computer Society, Technology Management Council, and WIE. He is a member of PMI, and a certified PMP. His professional interests are in systems architecture, embedded systems, technical education, technical management, strategic planning and the use of the web, collaboration tools and social networking to build a professional environment. He is presently consulting with and coaching organizations.

IEEE-HKN Professional Induction Ceremony

21 November 2015, New Brunswick, NJ

IEEE-HKN welcomed 25 new members as Professional Inductees during the November 2015 IEEE Board Series meeting held in New Brunswick, NJ.

Evelyn Hirt, IEEE-HKN 2015 Board of Governors President, inducted the following members in a ceremony held on 21 November of the IEEE Educational Activities Board. IEEE-HKN is proud to recognize the following individuals for their contributions to IEEE and the IEEE fields of interest.

Marc Apter
Amir Aghdam
Supavadee Aramvith
Karen Bartleson
Martin Bastiaans
Mary Ward-Callan
Carole C. Carey
Thomas Coughlin
Peter Eckstein
Margaretha Eriksson
Robert Hebner
Witold Kinsner
Susan K. (Kathy) Land
Paolo Montuschi
Murty Polavarapu
Pradeep Ramuhalli
Mary Ellen Randall
Marina Ruggieri
Emily Sopensky
W. Ross Stone
Scott Tamashiro
Ronald Tabroff
Enrique Tejera
Thomas Tierney
Ljiljana Trajkovic

In a separate ceremony held on 21 December 2015 at the IEEE Richland Section meeting, Dr. Zhenyu (Henry) Huang was inducted into IEEE-HKN by President Hirt.

IEEE-HKN extends our congratulations to all new Professional Inductee Members!

New IEEE-HKN Chapters

The following Universities were approved by the IEEE-HKN Board of Governors to establish IEEE-HKN chapters.

National Technical University of Athens (NTUA) -Mu Gamma

Singapore University of Technology and Design (SUTD)-Mu Epsilon

Eastern Washington University - Mu Delta

Western Washington University - Mu Zeta

University of KwaZulu-Natal (UKZN), Howard College Campus, Durban, South Africa –Mu Eta

The chapter installation ceremony at the Mu Epsilon chapter at Singapore University of Technology and Design (SUTD) was held on 14 December 2015. Eleven student members, one faculty advisor and an IEEE representative member from the IEEE Singapore headquarters were inducted. This Chapter was formally installed by the 2015 IEEE President and CEO, Howard E. Michel, and Associate Provost of SUTD, Professor Lim Seh Chun.

The Mu Zeta chapter installation ceremony at Western Washington University was held on 15 January 2016, and nine student members and two faculty members were inducted by IEEE-HKN 2015 President Evelyn Hirt. IEEE-HKN welcomes these new chapters and members, and looks forward to additional installation ceremonies in 2016.

IEEE Educational Activities Board (EAB) Awards

Highlights from the November 2015 IEEE EAB Awards Ceremony

IEEE-Eta Kappa Nu, IEEE's Honor Society, has numerous award programs designed to promote and encourage educational excellence in electrical and computer engineering. These awards recognize outstanding accomplishments by students, professors, and industry professionals who make significant contributions to society, and who exemplify a balance of scholarship, service, leadership, and character. IEEE-HKN encourages chapters and individuals to nominate all eligible candidates; for a full list of IEEE Educational Activities Board Awards, visit EAB Awards. The deadline for 2016 IEEE EAB and IEEE-HKN Award nominations is 2 May 2016. Nominate a deserving candidate today!

At the IEEE EAB Awards dinner held on 20 November 2015 in New Brunswick, NJ, IEEE-HKN presented the following awards: Outstanding Young Professional Award; C. Holmes Macdonald Outstanding Teaching Award; and Eminent Member Recognition.

2015 IEEE-HKN Outstanding Young Professional Award was presented to Payman Dehghanian *"for research on reliability-centered maintenance to improve cost effectiveness in the electric power industry."*

From left to right: Dr. Saurabh Sinha, 2015 IEEE VP, Educational Activities; Payman Dehghanian; Evelyn Hirt, 2015 President, IEEE-HKN Board of Governors; Karen Panetta, Chair, 2015 IEEE EAB Awards and Recognition Committee

Mr. Payman Dehghanian received his BS degree from the University of Tehran, Iran (2009), and his MSc degree from the Sharif University of Technology, Tehran, Iran (2011); both in Electrical Engineering. Since 2012, Payman has been pursuing his PhD degree in Electrical Engineering at Texas A&M University. His research interests include electric power system protection and reliability, asset management, maintenance scheduling, renewable energy integration, and smart electricity grid applications.

Payman is the author of two books on electrical engineering for students and has translated one book from English to Persian on "Probabilistic Power Transmission System Expansion Planning." He has authored ten journal papers and has published or presented more than 38 papers in meetings and conferences worldwide.

2015 IEEE-HKN C. Holmes MacDonald Outstanding Teaching Award was presented to Dr. Preethika Kumar *"for dedication to fostering student success through the development of state-of the-art courses, creation of stimulating classroom environments, and personal attention to every student."*

From left to right: Dr. Saurabh Sinha; Preethika Kumar; Evelyn Hirt; Karen Panetta

Dr. Preethika Kumar is Associate Professor, Department of Electrical Engineering and Computer Science at Wichita State University, Kansas, US. Her research interests are in quantum computing architectures, designing one dimensional and two dimensional architectures for quantum computing, quantum shift registers and wires for quantum state transfer, quantum error correction and fault-tolerant quantum computing and physical implementations of algorithms on a quantum computer. Preethika believes that by the end of a semester, her students should have a balanced experience consisting of three components--a good grasp of the theory, a good feel for practical application of the theory applied to real-world problems, and a good awareness of how the course relates to other engineering courses in their curriculum.

IEEE-HKN Eminent Member Recognition was bestowed upon Dr. Asad M. Madni *"for technical attainments and contributions to society through outstanding leadership in the profession of Electrical and Computer Engineering."*

Dr. Asad Madni served as President, Chief Operating Officer and Chief Technology Officer of BEI Technologies Inc., CA from 1992 until his retirement in 2006. He led the development and commercialization of intelligent micro-sensors and systems for aerospace, industrial and transportation industries, including the Extremely Slow Motion Servo Control System for Hubble Space Telescope's Star Selector System which provided the Hubble with unprecedented accuracy and stability, resulting in remarkable images that have enhanced our understanding of the universe; and the revolutionary MEMS GyroChip® technology which is used worldwide for Electronic Stability Control and Rollover Protection in passenger vehicles. Prior to BEI, he was with Systron Donner Corporation for 18 years in senior technical & executive positions, eventually as Chairman, President, and Chief Executive Officer. There, he made seminal and pioneering contributions in the development of radio frequency and microwave systems and instrumentation, which significantly enhanced the Combat Readiness of the US in services.

Dr. Madni is currently an Independent Consultant; Distinguished Adjunct Professor/ Distinguished Scientist at UCLA; and Executive Managing Director & Chief Technical Officer of Crocker Capital. He is credited with over 170 refereed publications

From left to right: Dr. Asad Madni; Mrs. Taj Madni; S.K. Ramesh, 2016 President, IEEE-HKN Board

in archival journals, 69 issued /pending patents, and is the recipient of numerous national and international honors. He was elected to the U.S. National Academy of Engineering for "contributions to development and commercialization of sensors and systems for aerospace and automotive safety," (2011), and he was elected Fellow of the National Academy of Inventors for "demonstrating a highly prolific spirit of innovation in creating or facilitating outstanding inventions that have made a tangible impact on quality of life, economic development and the welfare of society" (2014). He is a Fellow/ Eminent Engineer of 14 of the world's most prestigious professional academies and societies.

The IEEE-HKN Alton B. Zerby and Carl T. Koerner Outstanding Student Award

The IEEE-HKN Alton B. Zerby and Carl T. Koerner Outstanding Student Award recognizes outstanding scholastic excellence and high moral character, coupled with demonstrated exemplary service to classmates, university, community, and country. This program is administered by the IEEE-HKN Los Angeles Area Alumni Chapter.

The winner of the 2015 Alton B. Zerby and Carl T. Koerner Outstanding Student Award is

Sara Kouroupis, Xi Chapter, Auburn University.

Sara is originally from Ellicott City, MD and completed her undergraduate degree at Auburn University. She graduated from the Honors College with a Bachelor of Electrical Engineering and a minor in Business Engineering Technology. While at Auburn, Sara held leadership positions in organizations including Eta Kappa Nu, the Society of Women Engineers, the Student Alumni Association, and the University Program Council. She also worked at the Auburn University Recreation and Wellness Center where she taught group fitness classes and performed administrative duties. In 2015, Sara received the Auburn University College of Engineering President's Award and was the Auburn University Electrical Engineering Student of the Year.

Currently, Sara is employed by the Johns Hopkins Applied Physics Laboratory and is working in the Space Department on the Space-Based Kill Assessment, where she performs optical sensor calibration tests and models signature data. She is also enrolled in a Master's program at Johns Hopkins University for a graduate degree in Electrical Engineering.

Sara will receive her award at the 2016 Electrical and Computer Engineering Department Head Association (ECEDHA) conference to be held at the Hilton La Jolla Torrey Pines in La Jolla, California, in March 2016. Congratulations, Sara!

IEEE-HKN will also present the IEEE-HKN Outstanding Chapter Awards at the ECEDHA meeting.

IEEE-HKN would also like to recognize the following students who were named as Honorable Mention and Finalists for this year's award.

Honorable Mention:

Thomas Foulkes, Epsilon Eta Chapter, Rose-Hulman Institute of Technology

Keenan Johnson, Gamma Theta Chapter, Missouri S&T

Finalists:

Tyler Przybylski, Delta Rho Chapter, University of North Dakota

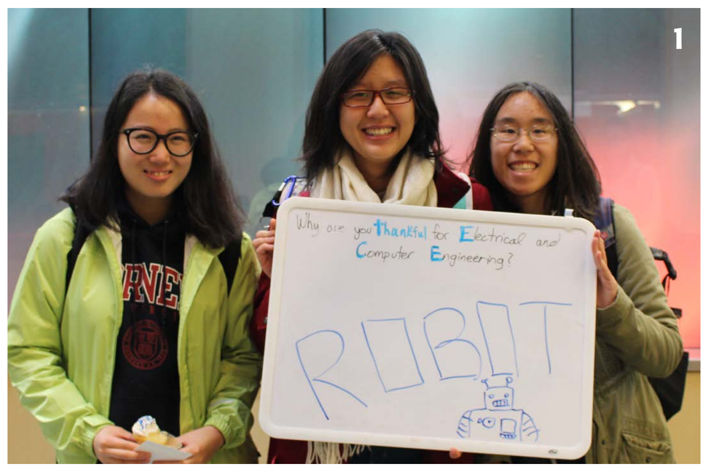
Andrew Fang, Mu Chapter, University of California, Berkeley

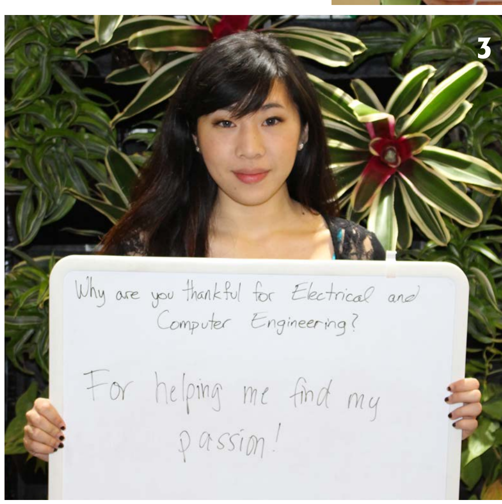
George Montgomery, Epsilon Omicron, University of Delaware

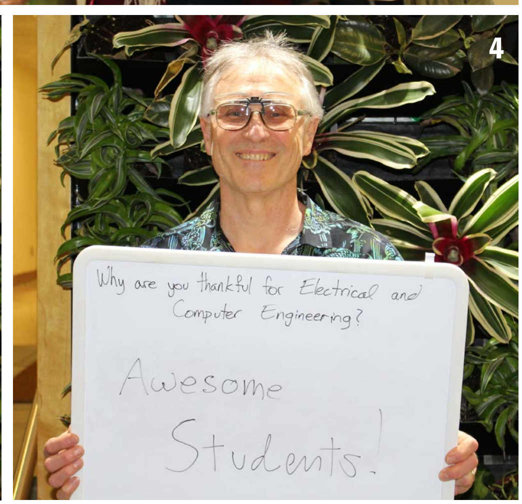
Founders Day, Cornell University, Kappa Chapter

By Ava Tan, Cornell Eta Kappa Nu Vice President

Every year on October 28th, chapters of IEEE-Eta Kappa Nu from around the world celebrate the founding day of the premier international electrical and computer engineering honor society. The Kappa Chapter of Eta Kappa Nu at Cornell University organized a fun day of festivities, incorporating participation from the eclectic engineering student body, faculty, and administration. Within the atrium of the main engineering building, Duffield Hall, members of Kappa Chapter set up a booth decorated with balloons, posters, and other HKN paraphernalia to showcase the organization. Kappa Chapter members had collaborated the day beforehand to decorate cupcakes with the letters of the organization, and on Founders Day they distributed the cupcakes to students passing by the booth. HKN members also distributed flyers to advertise upcoming Kappa Chapter workshops and tutorials on tools such as git, Linux, and LaTeX. Most notably, the members simultaneously orchestrated a photo campaign to encourage students to reflect upon the profound societal advancements brought about by electrical and computer engineers within the last century. Students and staff were asked to consider the question "Why are you thankful for electrical & computer engineering?" and a wide variety of insightful responses were recorded. Participants of the photo campaign wrote their answers to the question on a whiteboard using erasable markers, posed with the whiteboard, and members of HKN snapped photos to archive the participants' responses. By involving students, faculty, and staff alike in the photo campaign, Kappa Chapter members were able to bring together diverse communities of people within the College of Engineering to take a few moments and appreciate the proliferation of technology in modern society. All in all, Kappa Chapter's Founders Day festivities were a great success!







1 Kate Zhou, Sophia Yan, Christine Hwang; Cornell MechE B.S. 2016, Cornell ECE B.S. 2016, Cornell ECE B.S. 2016; **2** Shiva Rajagopal, HKN Kappa Chapter President, Cornell ECE M.Eng 2016; **3** Ava Tan, HKN Kappa Chapter Vice President, Cornell ECE B.S. 2016; **4** Dr. Bruce Land, Cornell ECE Faculty (teaches ECE 4760 - Digital Systems Design using Microcontrollers).

Barry L. Shoop

Dr. Barry L. Shoop, P.E.; IEEE President and CEO

MEMBER PROFILE

For more than thirty years, IEEE Fellow Barry L. Shoop has been a member of and leader within the global IEEE community. As Chair of the RAB/MGA Transformation Ad Hoc Committee, he led the transformation of the Regional Activities Board (RAB) into the Member and Geographical Activities Board (MGAB). During his tenure as Vice President of MGA, Barry was the architect of MGA's Regional Geographic Strategy, and created the Metropolitan Area Workshops. Additionally, as IEEE Secretary, he restructured IEEE's Governance Committee to improve the efficiency and effectiveness of IEEE governance.

Barry received his Ph.D. from Stanford University and B.S. from the Pennsylvania State University, both in electrical engineering. During his tenure at West Point, he has served in a number of leadership positions including Director of the Electrical Engineering Program and Director of the Photonics Research Center. He is currently Professor of Electrical Engineering and Head of the Department of Electrical Engineering and Computer Science, responsible for an undergraduate academic department with over 79 faculty and staff supporting ABET accredited programs in electrical engineering, computer science, and information technology.

Earlier in his career, he was a satellite communication engineer responsible for the design and installation of a high-capacity, global digital communication network, and also the CTO for a US$4.5B organization addressing the Improvised Explosive Device (IED) challenge worldwide.

In addition to being an IEEE Fellow, Barry is also a Fellow of the Optical Society of America (OSA) and the International Society for Optical Engineering (SPIE). In 2008, OSA recognized Barry with their Robert E. Hopkins Leadership Award and, in 2013, he earned both the SPIE Educator Award and the IEEE Haraden Pratt Award. He holds a patent on photonic analog-to-digital conversion and has authored over 150 archival publications as well as 8 books and book chapters. He is a licensed Professional Engineer in Virginia, USA.

Why did you choose to study the engineering field (or the field you studied)?

In high school, at the encouragement of my father, I enrolled in the vocational technical program studying electronics. I thoroughly enjoyed the hands-on aspect of the field and during my senior year, my electronics teacher recommended the electrical engineering program at the local campus of the Pennsylvania State University.

It was there that I developed a deep passion for the field of electrical engineering. When you think about it, engineering is an honorable profession – engineers solve real-world problems on a daily basis – engineers create wealth – engineers take ideas and make them reality – engineers create the future and ultimately advance technology for humanity!

What do you love about the industry?

In a word: diversity. Diversity of disciplines, diversity of practitioners, and the diversity of ways in which each of us can contribute not only to our respective profession, but to our world. My love of engineering has led to my work on projects large and small, around the world, spanning a host of engineering disciplines. I've been fortunate enough to work with and learn from extraordinary engineering, scientific, academic, and business leaders, and each experience is a new and valued one.

What don't you like about the industry?

I think that some in our industry have a very narrow and parochial view of the singular importance of technology itself – that somehow the technology or the technological solution is necessary and sufficient. Fundamentally, however, engineering is a human endeavor; one that must include and embrace the human dimension. In 1959, C. P. Snow delivered the Cambridge University Rede Lecture entitled "The Two Cultures and the Scientific Revolution," warning that practitioners from the sciences and the humanities needed to build bridges to further the progress of human knowledge and to benefit society. This perspective is even more important today. Previously, technology played a secondary and supportive role while social, political and cultural dimensions played a primary role. Today, technology is actually leading these dimensions in the influence on humanity. One only needs to read the newspaper to see influences of technologies like personal communication, robotics, distributed computing, cyber and others on the day-to-day lives of humans.

Whom do you admire (professionally and/or personally) and why?

We are fortunate to be part of a profession with an incredibly rich heritage. In a letter to Robert Hooke in 1676, Isaac Newton penned the phrase "If I have seen further than others, it is by standing upon the shoulders of giants." My professional giant is James Clerk Maxwell whose life work included laying the foundations for electromagnetic wave theory but also included remarkable contributions to thermodynamics, the world's first color photograph, control theory and even Scottish poetry.

On the personal side, my father is the one whom I admire most. He was a career truck driver but it was his vision and sage advice that set me on the path to becoming an electrical engineer. In addition, I truly admire my immediate family – my wife Linda, son Brandon and daughter Aubrey. They are truly my heroes. They have provided sage advice and honest and critical feedback, kept me grounded and humble, been my inspiration, taught me the importance of balance, and ultimately made me both a better professional and person. My children have also kept me young at heart!

There have been a great number of professionals who have played key roles in shaping my career — too numerous to mention. They all, however, contributed to me as both a professional and as a person. Some showed me how to work with and lead others; some taught me the importance of lifelong learning; some simply shared their expertise and experience with me, and helped me to become a better professional.

How has the engineering field changed since you entered it?

Today, there are more opportunities, in more engineering fields of interest, than perhaps ever before in the history of engineering. When I earned my doctorate, we saw innovations occurring every year or every few years. Today, we seem to be measuring innovation by the month. It is an incredible pace, and it's very inspiring to see.

In what direction do you think that the engineering and other IEEE fields of interest are headed in the next 10 years?

I see nothing but promise for engineering and the other IEEE fields of interest in the coming decade. In-

> Engineering is a full-contact, team sport that succeeds by integrating diversity in its broadest sense.

tel's Futurist, Brian David Johnson, predicts that the size of meaningful computational power will approach zero by the year 2020. Think of the possibilities and opportunities this will provide across all of our fields of interest!

One specific area where I believe we will continue to see remarkable advances is in the area of biomedical engineering. This is a field in which we're seeing the biological and the technological coming together like never before. It's going to change lives—and save them as well.

What is the most important lesson you have learned during your time in the field?

That engineering is a full-contact, team sport that succeeds by integrating diversity in its broadest sense. All too often people think engineers are hermits who would rather spend their time with equations and hardware in a lab. The most successful engineers work in interdisciplinary teams and embrace diversity of perspective in their design solutions. Each individual views a specific problem through their personal lens of disciplinary background and experience. Successful design teams include a wide-variety of engineering disciplines but can also benefit tremendously from disciplines like philosophy, psychology and other humanities and social sciences disciplines. These individuals bring a perspective on the human dimension to the engineering solution.

What advice can you offer recent graduates entering the field?

Focus on the things that fuel your passion. There is a reason you chose to pursue an education in some facet of engineering. Follow up on that, and dive as deeply as you can into that field, and see where it takes you. If you find an interesting tangent to explore—the intersection of your field with another emerging technology, perhaps—explore that new tangent. See where it takes you.

Most importantly, though—never stop learning. Treat your professional career as an extension of the classrooms you've just left. The best engineers working today are those that believe that learning is a journey that they will always be on. No matter how much they learn, not matter how much they advance technology, they always try to learn more, to make the next advance even more beneficial to our world.

If you weren't in your current field, what would you be doing?

I honestly cannot imagine doing anything else. I truly enjoy the colleagues, the challenges associated with solving real-world problems, and the immense satisfaction that comes from being an engineer.

I am reminded of the description that Herbert Clark Hoover suggested of the engineering profession: "It is a great profession. There is the fascination of watching a figment of the imagination emerge through the aid of science to a plan on paper. Then it moves to realization in stone or metal or energy. Then it brings jobs and homes to men. Then it elevates the standards of living and adds to the comforts of life. That is the engineer's high privilege."

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

… read more, learn more, laugh more, experience more, and contribute more.

Ralph Waldo Emerson wrote of success: "What is Success? To laugh often and much; to win the respect of intelligent people and the affection of children; to earn the appreciation of honest critics and endure the betrayal of false friends; to appreciate beauty; to find the best in others; to leave the world a bit better, whether by a healthy child, a garden patch or a redeemed social condition; to know even one life has breathed easier because you have lived; this is to have succeeded."

STUDENT MEMBER PROFILE

Elsa Torres

President of IEEE-HKN Lambda Rho Chapter at Tecnologico de Monterrey

Elsa Torres is a Doctoral Student of the Information and Communications Technologies Program at Tecnologico de Monterrey in Monterrey, Mexico. She has a B.S. in Electronic and Communications Engineering and an M.S. in Electronic Systems with major in Telecommunications from Tecnologico de Monterrey (1998 and 2002, respectively). As a student, her research focus is on Wireless Communications and has been actively involved in the honors society IEEE-HKN (Lambda Rho Chapter). Her professional experience of 7 years at the company Rohde&Schwarz (in which she offered several training courses) motivated her to improve her knowledge in order to share them with others. She is the current President of IEEE-HKN Lambda Rho Chapter at Tecnologico de Monterrey, also the Advisor of Women in Engineering Student Branch Affinity Group at Tecnologico de Monterrey, and the Secretary at IEEE Monterrey Section.

Why did you choose to study the engineering field (or the particular field you are studying)?

Since I was a girl, I have loved science, especially Mathematics and Physics, and I used to draw flowers but also smiling robots!. Once I was studying the junior high I had a technical lab on Electronics and it really got my attention. But my research area and passion, Telecommunications, came to my life in a very interesting way, the movie "Contact" with Jodie Foster really impacted my life in an impressive way, I dreamed one day I would be working with signals just the way she did.

What do you love about engineering?

What I love about engineering is that science is always present, and that you can rely on science always! In addition engineering helps to make the world a better place to live on! As an engineer I do not use the word "impossible", because I always try to find a solution with all my resources.

What don't you like about engineering?

Sometimes, to be an engineer is equivalent to be a solitary person and to be in a way incomprehensible. Our ideas will not always be accepted and understood. These effects are a little bit more intense when conducting research work. Also, being a woman in engineering, increases these factors.

As an engineer I do not use the word "impossible", because I always try to find a solution with all my resources.

What is your dream job?

Definitely my dream job is related to Wireless Communications, no matter if it is on research, academia or industry, but what I treasure about it, is to have the opportunity to share my knowledge with others.

Whom do you admire (professionally and/or personally) and why?

I admire people around me, people that share some of their distinctive features like humility, honesty, compromise, gratitude and optimism. Neither the diplomas, grades, money or prizes makes anyone be a better person. What makes you be a better person, in my opinion, is what you leave in other people's lives.

In what direction do you think the engineering and other IEEE fields of interest are headed in the next 10 years?

In my opinion, Information is the critical piece in the next generation technologies. Currently the amount of information is increasing at a very high speed every day, and people will require new algorithms and devices to share, generate and manage that amount of information.

IEEE-HKN Member, Elsa Torres

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What is the most important thing you've learned in school?

In my life, I have learned different things from school. As a girl, elementary school taught me the basics of science and I will always be thankful with those teachers who patiently introduced me to mathematics. In junior high, I remember as if it was yesterday the Electronics Lab and the mathematics class in which I learned trigonometry, definitively those moments impact my entire life. In high school, I had the privilege that my father was also my teacher of a computer class and those lessons will never be forgotten as they form the base on which I developed my computer skills. In the university the character is completely formed by those strict professors and their perfect lessons. But what I most value of school is to have the opportunity to meet all of those professors who leave in me the bright light of knowledge.

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

Telecommunications is a beautiful research field, people will always try to communicate with others no matter the distance and the conditions, people will always look to be present and near their loved ones, and the telecommunications engineer or researcher in this area has the knowledge to offer those connectivity means so that people get to meet others with the best possible way (quality of service).

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

If I had more time I would like to make paintings, teach science to other people, help humanitarian causes, travel in order to know more about me and finally share more time with my loved ones.

IEEE-Eta Kappa Nu Reminders

Chapter Management News

All Chapter management forms are now available for digital submission at www.hkn.org!

Required Forms

- Student Inductee Documentation – For each Induction Ceremony held
- Notice of Election of Officers – Submit this form every time Chapter Elections are held.
- Annual Chapter Report – Deadline: 30 June

Awards

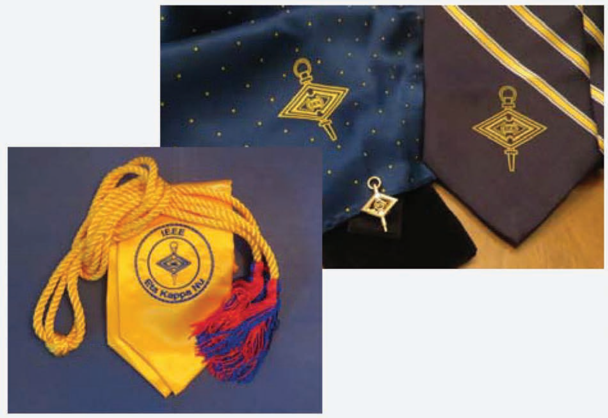
- Outstanding Young Professional Award Nomination Form – Deadline: The Monday following 30 April
- Outstanding Student Award Nomination Form – Deadline: 30 June
- Outstanding Teacher Award Nomination Form – Deadline: The Monday following 30 April
- Karapateoff Outstanding Technical Achievement Award Nomination Form – Deadline: The Monday following 30 April
- Outstanding Chapter Award Nomination – Deadline: 30 September

Other Forms

- New Pledge Form – Submit pledge information and IEEE-HKN Headquarters will send pledges a personal invitation to the submitting Chapter!
- Professional Member Induction Form – For non-student new inductees.
- IEEE-HKN Certificate Replacement Order Form

IEEE-HKN Store

- **Honor Stoles & Cords** – Order early to ensure timely delivery! Rush orders accepted.
- **Pins**
- **Logo Clothing**



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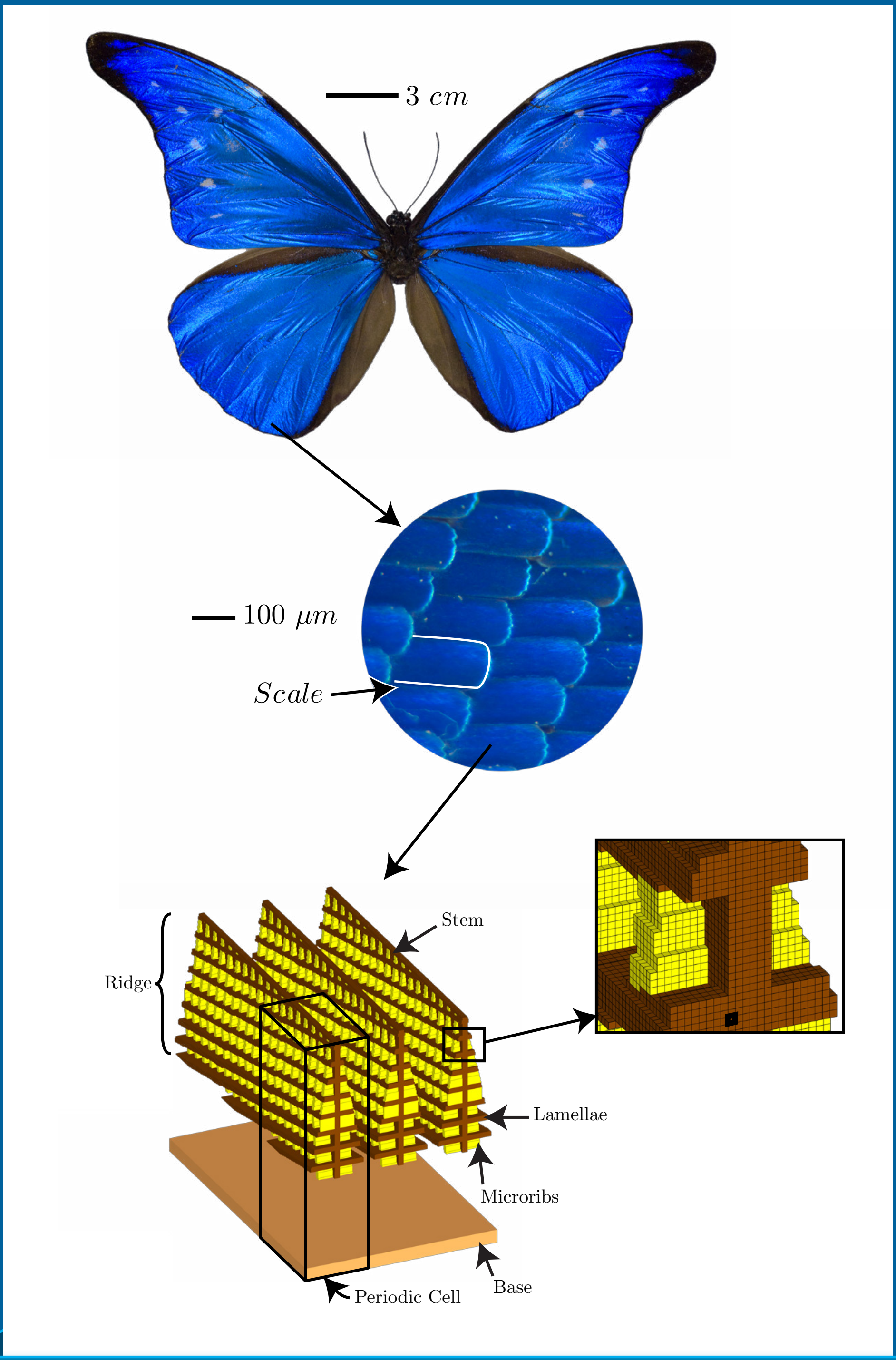
Chapter News: Let us know what is happening at your chapter!



STRUCTURAL COLOR

The scales on this butterfly's wings produce color through light interference from microstructures. Understanding of this natural design provides an engineering alternative to color pigments.

Image Courtesy of Dr. R. Todd Lee, Georgia Tech Research Institute