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THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

ETA KAPPA NU

SENSORS AND SENSING

Terahertz Range Weak Reflection Optical Fiber Structures for Distributed Sensing

Mechatronic Design of an Actuated Biomimetic Length and Velocity Sensor

Unconventional Biosignal Sensing with Passive RFID Tags

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THE BRIDGE

The Magazine of IEEE-Eta Kappa Nu

October 2016 – Sensors and Sensing

FEATURES

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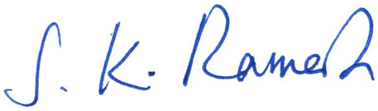
Greetings,

Welcome to the October 2016 issue! This has been a busy and productive year for IEEE-HKN by all measures. I was looking at the IEEE membership development report from June 2016 that shows that the number of student members in IEEE-HKN increased from 1,980 last year to 2,259 this year; an increase of 14%. The number of higher grade members who belong to IEEE-HKN jumped from 7,157 a year ago to 7,419 this year; an increase of 3.7%. Overall, the number of IEEE-HKN members registered a 5.6% increase over the past year with a current membership of 9,678. What is remarkable about this statistic is that the overall membership in IEEE during the same period dropped by 0.3% to 291,099, due in large part to the decrease in the number of members, graduate students and associate members. One of our strategic priorities of your Board of Governors is to focus on "value proposition" -- in other words, "What impact do we want IEEE-HKN to make?" What is the present IEEE-HKN member experience, and what can we do to make it even better? Based on the membership trends, it is clear that IEEE-HKN is playing a significant role in attracting and retaining members in IEEE. More importantly, IEEE-HKN is making a difference through the amazing contributions of our members to society. We will continue to hone in on this fundamental value proposition as it is vital to the success and future of IEEE-HKN.

This is also the time of year when several of our student chapters worldwide hold their induction ceremonies and welcome new members to the Society. Remember that you can induct professional members into your chapters as well, based on their work and contributions in IEEE's fields of interest. The Board of Governors has inducted several professional members into IEEE-HKN (the Eta Chapter) during the past year; most recently during the IEEE Board meeting in June. Professional members are an incredible asset to IEEE-HKN as they can help support local chapters where they live and work. During the past few months, the Board has been working diligently on the top priorities to establish financial security and fully integrate IEEE-HKN into IEEE; and, we are making good progress. If you haven't been to our web page lately, please take a moment to check out the changes we are making and let us know what you think. In closing, I am delighted to inform you that our signature publication -- THE BRIDGE, has been selected for a 2016 APEX Award, making it the third year in a row that we have been selected for this prestigious award. Congratulations to the entire team for their amazing work! We will be celebrating in November as we recognize the recipients of the IEEE-HKN Outstanding Teaching Award and the IEEE-HKN Young Professional Award. Stay tuned for more information in the days ahead. Meanwhile, thank you for making IEEE-HKN the premier Honor Society we can all be proud of!

Best wishes,



2016 IEEE-HKN President

Steve E. Watkins

Gamma Theta Chapter

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Dear Eta Kappa Nu Members and Friends,

The February 2015 issue of THE BRIDGE magazine was recognized with a 2016 APEX Award of Excellence in the writing series category of this international competition for communication professionals. The original papers for this series were: "Growing the Smart Grid Workforce" by Peter W. Sauer; and "Smart Grid: The Role of the Information Sciences" by H. Vincent Poor. If you are interested in improving your understanding of smart grid technologies, I recommend these papers. An archive of recent issues can be found on our website. Thank you to our authors for providing such noteworthy content for the magazine.

This issue of THE BRIDGE has a theme of "Sensors and Sensing." We have features that discuss sensors based on fiber-optic structures, bio-signal sensing, and bio-inspired mechatronics. These works highlight the interdisciplinary aspects of engineering design. Effective collaboration across disciplines requires proficiency at communication and a working knowledge of connecting concepts. Assumptions and constraints need to be clearly conveyed -- even terminology can be an issue. For instance, "high frequency" may have a different meaning for an electrical engineer, as opposed to a civil engineer.

Many of the current developments for sensors and sensing instrumentation target dedicated applications in which the hardware and software must be efficiently tailored to the intended use. Requirements for weight, size, networking, computation, power, etc. provide challenging engineering problems. Wearable devices for bio-signal monitoring and embeddable sensors for structures are just two examples of how such technology can benefit society. The multi-layer sensor node in the photograph is an example of a low profile, adaptable system with data sensing, data processing, and wireless networking capabilities. It is configured for data from an electrical strain gage as might be used for an in situ structural monitoring application.

Regards,

Steve E. Watkins

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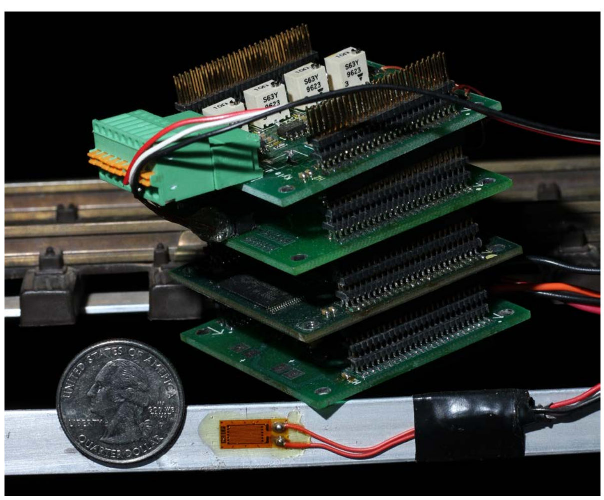

Multi-layer sensor node for embedded strain instrumentation. Courtesy of Dr. Kyle Mitchell, St. Louis University. For more information on this hardware see.

K. Mitchell, et al., "Embeddable modular hardware for multi-functional sensor networks," Smart Materials and Structures, **16**, N27-N34, (2007).

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Dear Readers:

People often ask me "I was HKN a long time ago, am I still HKN?", or "I was HKN in college, how do I renew or get involved?" Here is the great news -- HKN is a lifetime designation, once HKN -- always HKN! Once you are inducted into HKN, you carry that honor with you throughout your lifetime. You can proudly include your HKN (or IEEE-HKN post-merger) status and the name of your chapter when listing your honors and affiliations in your bio, CV, on your Facebook or LinkedIn page, or in your publications.

As you are always HKN, we invite you to get involved with your chapter, or a local chapter. We have many opportunities; our students and young professionals always need help, and welcome you to share your knowledge and engineering experience. There are also traditional volunteering opportunities to serve: on a committee; the Editorial Board of THE BRIDGE; or the IEEE-HKN Board of Governors. There are also MICRO-volunteering opportunities such as:

- Project Mentoring: Mentoring a student on a senior design or capstone project
- Chapter Mentoring: Working with your chapter or a local chapter on a program or event
- Guest Speaker: Speaking at regular chapter meetings or at campus events
- Bloggers and Social Media Contributors
- Contributing your HKN Memorabilia to our Archives
- Work Teams: We have several short term (2-3 month) work teams addressing alumni engagement, new website development, and program development.

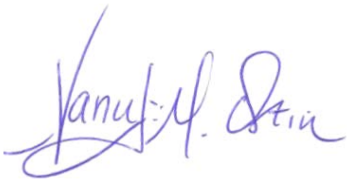
Visit our website to review these opportunities. Check out our new home page (click on the chapter page to find your chapter -- it's great!) Let us know how you wish to be involved.

Are you HKN and an IEEE Fellow? There is a new feature on the Fellows Directory -- you can filter IEEE Fellows who are HKN.

Let me also take this opportunity to recognize and thank S.K. Ramesh, our 2016 IEEE-HKN President. Ramesh has dedicated substantial time and energy to lead the Board of Governors and reach out to our students, chapters, faculty advisors, alumni, IEEE, and the engineering world not only to advance the mission and vision of IEEE-HKN, but also to establish a strong plan for our future and provide direction for our success. He will continue on the Board as our Past President, and work in conjunction with our 2017 President, Timothy Kurzweg to continue the vital work done this year and drive our organization to a successful future. It is a pleasure working with these very dedicated leaders and all of the volunteers of IEEE-HKN.

I am always happy to hear from you -- I appreciate your comments, ideas, and involvement!

Sincerely,



Director, IEEE-HKN

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Terahertz Range Weak Reflection Optical Fiber Structures for Distributed Sensing

by: Zhen Chen, Gerald Hefferman, and Tao Wei

Abstract

Optical fiber is a well-developed element of the communication infrastructure undergirding the modern world. However, the engineering applications of optical fiber stretch beyond communication applications. One such application is as a platform for distributed strain and temperature measurement. By resolving weak reflections at or above the Rayleigh level using coherent optical frequency domain reflectometry (C-OFDR), subtle changes in temperature and strain along the optical fiber can be measured. Supported by the National Science Foundation (NSF), researchers from the Next Generation Sensing Technology Laboratory at the University of Rhode Island have been working to develop sensor systems leveraging this beneficial attribute of optical fiber. To further enhance the signal-to-noise ratio of these sensor systems while maintaining minimal crosstalk between cascaded sensor elements, femtosecond laser micromachining techniques were used to modify the optical fiber by introducing weak reflection structures with periods corresponding to the terahertz range. The article describes several of these sensing structures, as well as their fabrication, interrogation, and experimental characterization.

Key words: fiber optics, distributed sensing, optical fiber gratings, optical fiber sensors

1. Introduction

Optical fibers have several characteristics that make them well suited to sensing applications. These traits include immunity to electromagnetic interference; mechanical, chemical, and thermal resilience; and low cost. This has led to optical fiber sensors finding scientific and commercial applications in a wide variety of fields, including robotic control, energy industry infrastructure, and surgical instrumentation [1-4]. The distributed measurement of temperature and strain occurs when this information is gathered along the entire length of the optical fiber probe. Using coherent optical frequency domain reflectometry (C-OFDR) as an interrogation technique, a single mode fiber (SMF) to be employed as a sensing probe in real time [5-10]. C-OFDR allows the weak Rayleigh backscattering pattern intrinsic to all optical fiber of an optical fiber under test can be amplified. This pattern can be correlated to distributed strain and temperature information. Using a highly coherent optical frequency sweep and a large interrogation bandwidth, high spatial resolution can be achieved.

Modifying the single mode optical fiber to include reflector structures along its length confers additional engineering benefits to an optical fiber sensing system, particularly an improved signal-to-noise ratio. These reflector structures include Fabry-Perot cavities and fiber Bragg gratings. By employing OFDR or synthesis of optical coherence function (SOCF) to interrogate these systems, weak reflectors can be used for the construction of sensor elements, allowing both signal-to-noise ratio and crosstalk between sensor elements to be improved [11, 12]. Grating structures with reflectivities of approximately –30 to –40 dB can be written using ultra-violet (UV) laser micromachining techniques, and large numbers of these reflectors can be cascaded along a single optical fiber probe.

More recently, femtosecond micromachining has allowed for the inline fabrication of a range of structures within optical fibers [13-15]. This method of inline inscription within optical fibers has been recently employed to fabricate a variety of optical fiber sensors [16-18]. Using femtosecond machining, high intensity energy can be precisely delivered to a focal point, leaving minimum damage to the surrounding material [19]. Ultra-short pulses are used to introduce refractive index changes within the optical fiber core. The reflectivity of these structures can be adjusted by varying the laser power used during inscription of the reflector elements within the fiber; the reflected signal level can be well controlled at 20 to 30 dB above the typical Rayleigh backscatter level to achieve an enhanced signal-to-noise ratio while maintaining good multiplexing capability by minimizing crosstalk. By interrogating these structures using a C-OFDR interrogation system, changes in the frequency domain spectra of these reflector structures can be resolved and used to measure temperature and strain changes along the fiber under test.

This article presents a series of terahertz-range weak reflection structures used for temperature and strain sensing. Each structure was interrogated using C-OFDR. Femtosecond laser micromachining techniques were employed in order to fabricate several differing weak reflector structures, including an intrinsic Fabry-Perot interferometer (IFPI), a terahertz-range fiber Bragg grating, and a phase-shifted fiber Bragg grating. Additionally, a novel a buffer intact fabrication technique is also described, which allows for the mechanical resilience of the optical fiber to be preserved after modification. [Key concepts are defined in Table 1.]

2. Interrogation and Fabrication

A. Sensor Interrogation

The schematic of the interrogation system, based on C-OFDR [20-22], is illustrated in Figure 1. Light from the tunable laser (TLS) is divided into a signal path and a clock path. The signal path is constructed with an interferometry structure using optical couplers (CPL) and an optical circulator (CIR). A polarization controller (PC) is used to maximize the output intensity of the signal path. A clock path is constructed using a fixed delay line to resample the data from the data path to compensate the non-linearity of the TLS sweep. The optical signals are collected by balanced photodetectors and a data acquisition (DAQ) card. Using this setup, the TLS sweeps from 1525 nm to 1555 nm, resulting in a 3.7 THz interrogation bandwidth. The AC-coupled voltage signal received by the DAQ can be expressed as:

$$v_{AC} = 2\eta r I_{ref} \sum_{m=0}^{M-1} \cos\left[\beta\left(z_{ref} - z_m\right)\right] \quad (1)$$

where η is the light-to-voltage coefficient of the photodetector, r is the reflectivity of the weak reflectors, I_{ref} is the light intensity of the reference arm, β is the propagation constant, z_{ref} is the length of the reference arm fiber, and z_m is the delay length of the m^{th} weak

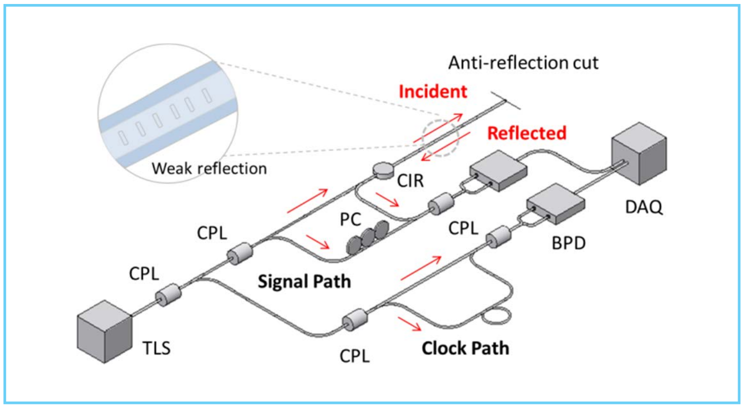

Figure 1. Schematic of the C-OFDR interrogation system

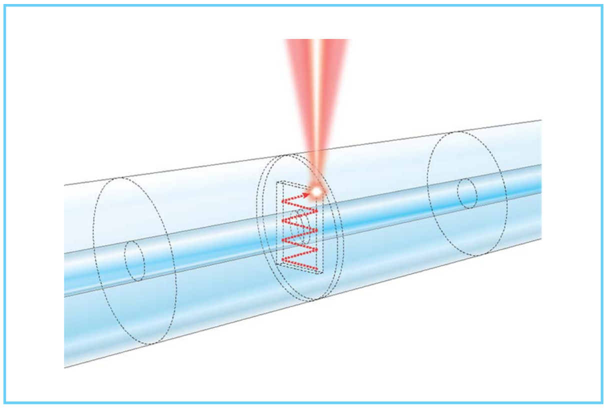

Figure 2. Illustration of the fabrication of weak reflector structures using femtosecond laser micromachining

reflection along the detection arm. In this model, a total of M weak reflectors are inscribed along the fiber under test.

B. Femtosecond Laser Micromachining

A Ti-Sapphire fs laser (Coherent, Inc.) micromachining system was used to create internal refractive index variations, e.g. intrinsic structures, that serve as weak reflectors. Lengths of single mode fiber (Corning, SMF-28) were used with core and cladding diameters of 8.2 μm and 125 μm, respectively. The central wavelength, pulse width, repetition rate, and maximum power output are 800 nm, 200 fs, 250 kHz, and 1 W, respectively. A half-wave plate, a polarizer, and several neutral density filters were used to adjust the output power. The laser was switched on and off by electrically gating the internal clock. Before the sensor fabrication process, the fiber to be modified was mounted on a three-axis translation stage (Newport, Inc.) and the buffer coat stripped. A cuboid

Table 1 Descriptions of Key Concepts

Concept	Description
Rayleigh Backscattering	Rayleigh backscattering is an effect in which intrinsic, small-scale discontinuities of the refractive index of the optical fiber result are very weak. Changes in strain or temperature along the fiber can be resolved by measuring changes in these reflections.
Optical Frequency Domain Reflectometry (OFDR)	OFDR is a method of extracting useful information from a sensor by measuring the intensity of reflected laser light as a function of frequency. Changes in the resulting frequency spectra can be related to changes in strain and temperature along the length of the optical fiber.
Fiber Fabry-Perot (FP) Cavity	An FP cavity uses two reflectors cascaded along an optical fiber to generate an interference pattern via the superposition of light reflected from each surface. This interference pattern is sensitive to changes in length between the two reflectors, and thus is a useful tool for measuring changes in strain and temperature along the fiber.
Fiber Bragg Grating (FBG)	An FBG is similar to an FP cavity, but uses many reflectors instead of simply two. The result is the superposition of many waves, creating a peak in the frequency domain. This peak shifts as a function of strain and temperature along the fiber, allowing it to be used as a sensor.
Laser Micromachining	Laser micromachining uses high-power laser light to permanently alter the optical properties of an optical fiber. This allows a variety of structures, each with different physical attributes, to be inscribed within the fiber itself.

region was inscribed in the center of the fiber covering fiber core, as illustrated in Figure 2. The distance domain signals along the fiber under test were then extracted using a Fourier transform. Figure 3 shows the microscopic pictures and the distance domain reflection signals resulting from differing femtosecond laser powers (0.14 W, 0.12 W, and 1 W). The distance between inscribed weak reflector elements was in the millimeter range. This technique was employed in the fabrication of each of the following terahertz-range structures described below.

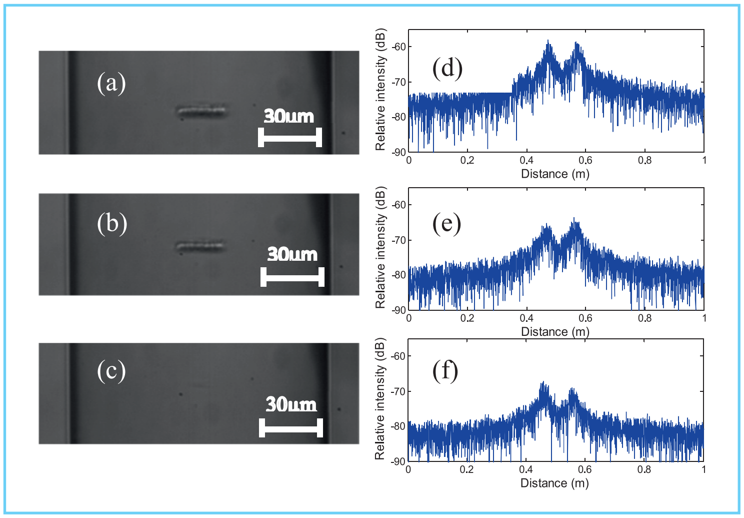

Figure 3. Microscopic image and reflection intensity in the spatial domain of three 1cm IFPI cavities fabricated using differing laser powers: (a) 0.14 W, (b) 0.12 W, and (c) 0.10 W

3. Sensor Structures

Introducing structures along the length of the optical fiber allows its optical properties to be fine-tuned, enhancing its utility as a sensing tool. Many potential modifications can be made in order to achieve this goal; this work used a subset of these modifications that are based on creating weak changes in reflective index, or discontinuities, within the optical fiber core. These changes in refractive index generate weak reflections of the incident laser light. By cascading two or more of these reflectors along the length of the fiber, an interference pattern is created by the superposition of each reflected wave. Changes in the distance between reflectors, which occur due to changes in strain or temperature along the fiber, result in changes in interference pattern measured as the photodetector. In this way, strain and temperature along the fiber under test can be resolved. Several distinct reflector structures, each of which operates via this general mechanism, are shown in Figure 4 and are described below.

A. Intrinsic Fabry-Perot Interferometer (IFPI)

A simple terahertz range sensing structure can be formed by cascading two weak reflectors along the length of an optical fiber as an intrinsic Fabry-Perot interferometric

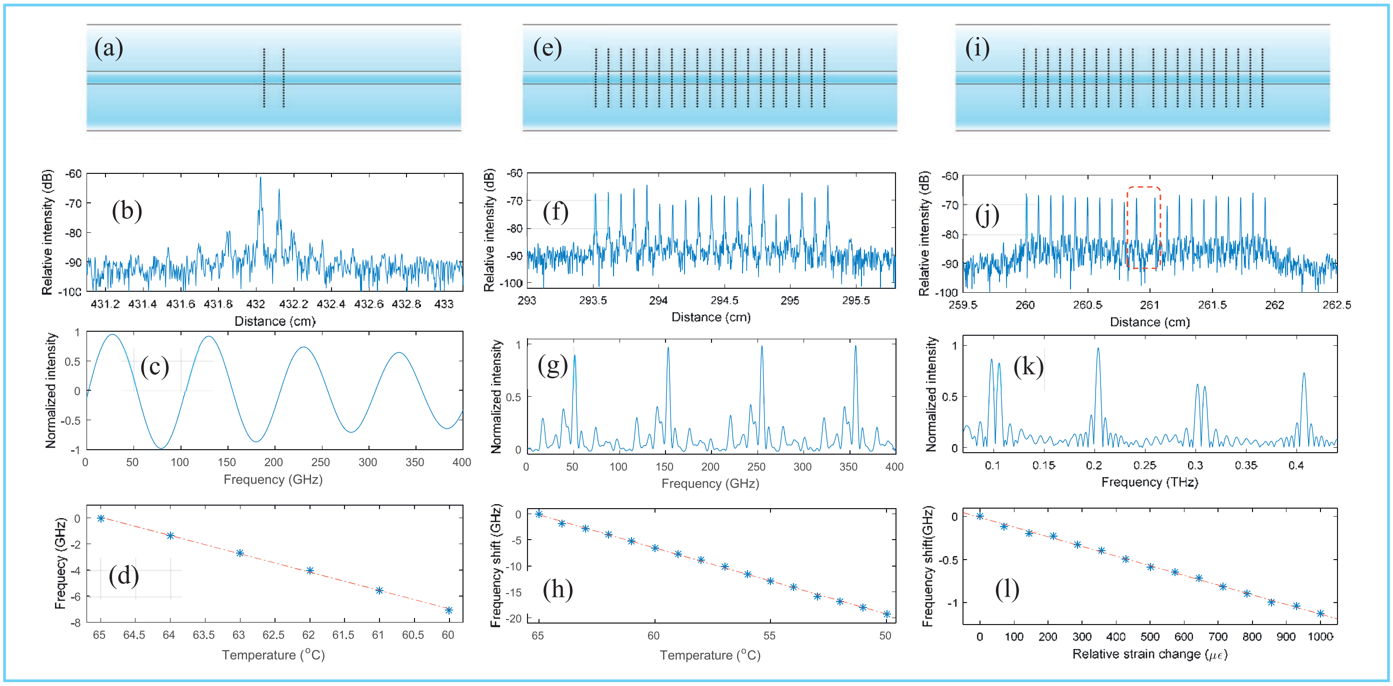

Figure 4. Schematic illustrations, distance domain signals, frequency spectra, and testing results of weak reflection structures; (a-d): intrinsic Fabry-Perot interferometer; (e-h): terahertz range fiber Bragg grating; (i-l): phase shifted terahertz range fiber Bragg grating

(IFPI) cavity [23]. Figure 4(a, b) show an example of an IFPI structure fabricated with a pitch length of 1 mm. The femtosecond laser power used to fabricate the structure was carefully adjusted to 0.11 W, resulting in a reflectivity of approximately -60 dB. Defining the Rayleigh scattering pattern power as the noise floor, the IFPI structure was measured to have a 30 dB signal-to-noise ratio. Simultaneously, the reflection is weak enough to allow cross-talk between individual IFPIs to be ignored, a beneficial feature for multiplexing applications. Figure 4(c) shows the frequency spectrum of the IFPI sample, which has a period of 100 GHz. Shifts in this frequency profile, extracted by tracking the zero-crossing point within one frequency period, can be related to changes in temperature along the length of the optical fiber. Highly linear results were found between frequency shift and temperature, shown in Figure 4(d), and the temperature sensitivity of the IFPI was calculated to be 0.0667 °C.

B. Terahertz-Range Fiber Bragg Grating (THz FBG)

To further enhance signal-to-noise ratio of the sensor system, a grating-based sensing structure can be introduced by cascading a series of weak reflectors to form a fiber Bragg grating [24]. Figure 4(e, f) shows an example of a THz FBG structure fabricated using 19 reflection points. The pitch length of the structure was 1 mm, resulting in a period of 100 GHz, shown in Figure 4(g). The full-width-at-half maximum (FWHM) of the resulting peak in the frequency domain of THz FBGs with different numbers of reflectors was experimentally studied. When pitch length and fabrication power of the femtosecond laser are held constant, an enhanced quality factor was be observed as the number of reflectors within each THz FBG structure was increased. Linear results were found in Figure 4(h). Compared with the earlier IFPI structure, the weak reflection THz FBG structure demonstrated an enhanced detection limit of 0.0017 °C.

C. Phase-Shifted Terahertz-Range Fiber Bragg Grating

Although both the IPFI and THz FBG structures maintain good signal-to-noise ratio and multiplexing capability, their 200 GHz period in the frequency domain limits their dynamic range. In order to increase the dynamic range of these structures, a shift can be introduced into the position of the reflectors of the THz FBG structure, resulting in a phase-shifted terahertz-range fiber Bragg grating [25]. This structure was fabricated by inscribing two 1 mm pitch length, 10 point THz FBGs along a single mode fiber using 0.11 W femtosecond laser power, and positioning the two gratings with 1.5 mm of distance between their neighboring reflectors, shown in Figure 4 (i, j) resulting in a phase shift. This phase shift results in an enhanced quality factor of the resonant peak in the frequency domain, allowing for lower order peaks to be used for measurement, increasing the dynamic range of the terahertz range sensing structure. Figure 4 (k) shows the frequency spectrum at these lower orders. Large strains of up to 1000 $\mu\varepsilon$ were tested, and linear results were found, as shown in Figure 4 (l).

D. Buffer Intact Fabrication Technique

Each of the three devices mentioned above were fabricated using the femtosecond laser only after the dual acrylate buffer coating surrounding the optical fiber had been removed. This allowed the energy of the femtosecond laser to be delivered to the silica of the optical fiber without being dissipated by the coating at the cost of substantially diminished mechanical resilience of the optical fiber. In order to maintain the mechanical resilience of terahertz range sensing structures, a buffer intact fabrication technique was studied [26]. To the authors' knowledge, this is the first time such structures have been introduced into optical fiber while the buffer coating was allowed to remain intact. In order to allow for the inscription of reflectors within the otherwise unmodified coated fiber, the femtosecond laser power was carefully adjusted so as to avoid delivering energy to the dual acrylate coating at a level sufficient to melt the buffer, while remaining capable of introducing weak reflections to the fiber core, illustrated in Figures 5(a) and 5(b). Compared with the buffer stripped fabrication technique using 0.11 W femtosecond laser power in Figure 5 (c), a reduced femtosecond laser power of 0.085 W was applied to fabricate the buffer intact THz FBG in Figure 5(e). Both strain and temperature tests were conducted using both coated and uncoated THz FBGs, which demonstrated highly similar results, shown in Figures 5(d) and 5(f).

4. Conclusions

To conclude, this article summarizes a series of terahertz-range weak reflection structures for distributed sensing applications. The interrogation system is based on the C-OFDR method, while femtosecond laser micromachining technique was employed to fabricate each sensor structure within single mode optical fiber. Interrogation and fabrication techniques were described and experimental results provided for each sensor structure. The buffer-intact approach reduces

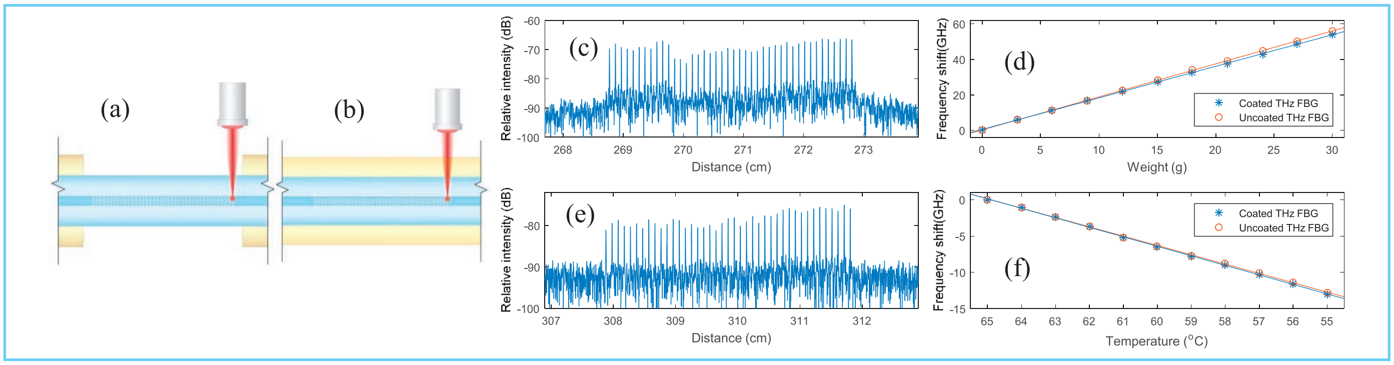

Figure 5. Buffer intact femtosecond laser fabrication: (a) and (b) schematic of fabrication with buffer stripped and buffer intact; (c) distance domain signal for THz FBG with buffer coating stripped; (e) distance domain signals for THz FBG with buffer coating intact; (d) and (f) strain and temperature testing results

the complexity and cost of fabricating such sensor structures and improves the mechanical strength of the sensors. These results demonstrate that terahertz range weak reflection structures hold substantial potential as sensor elements for distributed optical fiber sensing applications.

Acknowledgement

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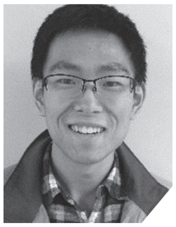
Author Biographies



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Mechatronic Design of an Actuated Biomimetic Length and Velocity Sensor

by: Kristen N. Jaax and Blake Hannaford

Abstract

Biological designs offer roboticists a rich source of mechanisms for the challenge of controlling movement. Our device draws upon this resource, modeling the muscle spindle, a biological sensor which transduces muscle length and velocity for kinesthetic awareness and movement control. The three core neural and mechanical elements of the muscle spindle are identified and implemented in precision engineering hardware using performance specifications derived from biological literature. Intrafusal muscle is modeled by a linear actuator fast enough to replicate muscle dynamics. Its step response exhibits 27 ms rise time and 9.2% overshoot. Sensory region transduction of strain into voltage is modeled by a strain-gauged cantilever 51μm thick. A voltage-controlled oscillator, encoding voltage as a frequency-modulated square wave, models action potential frequency encoding. The transducer exhibits the desired linear response with a 34-nm/Hz sensitivity. The three subsystems were combined to perform integrated systems testing. Driving the actuator with simple position control, the device detects trajectory-tracking errors introduced by phase lag and perturbation. Driving the actuator with physiologically based force control, the device successfully replicates the major features of muscle spindle response under ramp and sinusoidal position inputs. Applications include motor control research and novel sensor design for prosthetics and engineering.

Index Terms—Biorobotic, fusimotor, gamma motorneuron, intrafusal fiber, muscle spindle.

I. Introduction

IN BIOROBOTICS research, engineers and biologists come together to implement in steel and silicon the researcher's vision of the mechanisms driving a biological process. Such a project is instructive for all parties involved. Physiologists are able to test the viability and coherency of the proposed mechanisms when challenged with the demands of the physical world. Meanwhile, engineers are able to draw from this process novel approaches to age-old tasks, such as detecting the properties of the physical environment. This paper describes the development of such a biorobotic device, an actuated biomimetic length and velocity sensor, shown in Fig. 1. The design is based on length and velocity sensors found in mammalian muscle tissue, called muscle spindles. These organs contain a spring-like transducer region which lies in series with an internal actuator, the intrafusal muscle. This tiny actuator receives motor commands from the central nervous system (CNS), allowing the brain to actively modulate the nature of the output of the transducer's sensory region. The development of an engineering implementation of these sensors poses the following questions: What elements of the muscle spindle represent core functionality? How are these functional elements best implemented to form a robust robotic sensor? Finally, can a nonbackdriveable electromechanical system yield the active filtering and transduction behavior of living muscle and nervous tissue? We thus address the following hypotheses.

1. The core functions of a robotic length and velocity sensor based around a structural model of muscle spindles are mechanical filtering, transduction, and encoding. A sensor which captures these methods can exhibit the type of response seen in muscle spindles.
2. The electromechanical systems presented here are capable of achieving the performance specifications necessary to match the physiology of mammalian muscle spindles.

In this paper, we present the design, theory, and performance testing of the engineering subsystems comprising the mechatronic device. We also present performance results of the integrated system under two different controllers. First, we present a simple position-based controller for engineering testing of the hardware's performance. Second, we present performance results under a physiologically based controller tuned to accurately replicate muscle spindle performance. A second paper [1] documents the design and implementation of that physiologically based controller, and also compares the robotic muscle spindle's performance directly against comparable data from the biological muscle spindle literature.

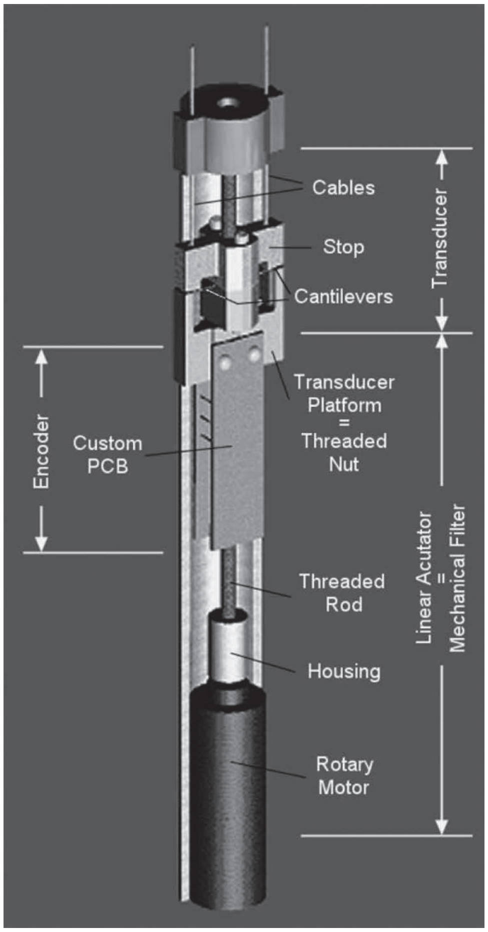

Fig. 1. CAD model of biomimetic sensor.

A. Background

The mammalian muscle spindle, shown in Fig. 2, consists of long muscle fibers, called intrafusal fibers, which run the length of the spindle. Each fiber contains a sensory region in the center, and an actuator region lying at either end. The sensory region acts as a passive linear elastic spring. Ia sensory nerve endings wrap around these fibers and transduce stretch of the sensory region into a depolarization of their membrane. Heminodes on the Ia axon then encode this analog depolarization into a frequency-modulated spike train of action potentials which travel up to the spinal cord.

The actuator region is essentially a normal muscle fiber, controlled by the input of a dedicated signal from the

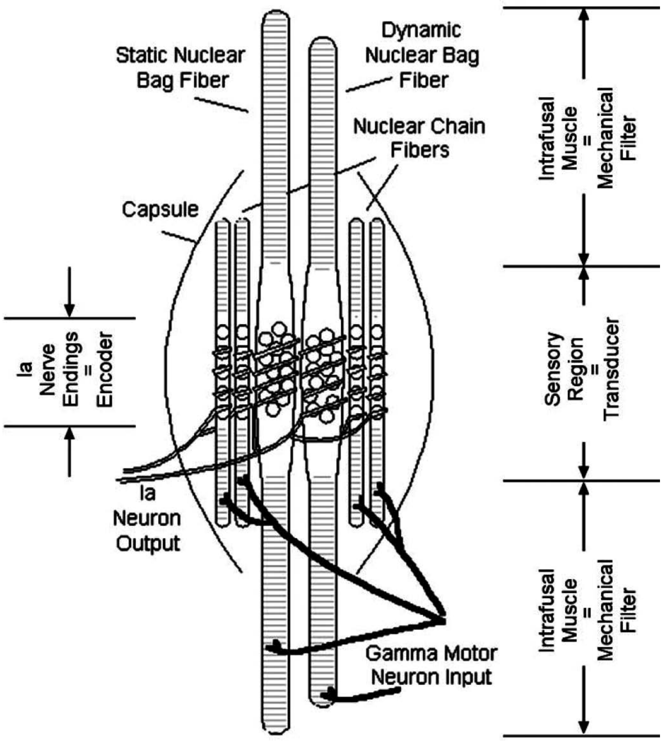

Fig. 2. Mammalian muscle spindle anatomy.

spinal cord, the γ motor neuron. The function of the actuator region is to filter incoming displacements, thereby conditioning the nature of the signal reported by the sensory transducer. The γ motor neuron control of the actuator's force production allows the CNS to finely control this process. For instance, it can raise the sensor's gain during challenging kinematic situations, e.g., walking across a narrow beam, by increasing contraction and thereby increasing the stretch of the sensory region [2].

Several mathematical models of the muscle spindle have been developed [3]–[5]. The Schaafsma model [4] is one of the most sophisticated models, consisting of a nonlinear extrafusal muscle in series with the noncontractile sensory element. This model, unlike the many linear models, is able to approximate muscle spindle behavior for a wide range of stimuli.

II. Methods

A. Design

Based on an earlier prototype [6], [7], we abstracted the three core elements of muscle spindle function: mechanical filtering, transduction, and encoding. The mechanical filtering, e.g., tuning the transducer to velocity inputs versus position inputs, is performed in the biological muscle spindle by the contractile region of the intrafusal fibers. Our goal is to create an internal actuator with performance specifications sufficient to allow reproduction of intrafusal muscle dynamics when driven by a physiologically based closed-loop controller. Based on the kinematics observed in intrafusal muscle response to mechanical stretching during direct observations [8], [9], this requires the following step response: a rise time (Tr) $<$ 30 ms, settling time (Ts) $<$ 150 ms, percent overshoot (P.O.) $=$ 10%, steady-state error (Ess) $=$ 0.

The transduction role in the biological muscle spindle is performed by strain-sensitive ion channels, which cause depolarization of the Ia nerve membrane in direct proportion to the strain applied across the sensory region [2]. The biological transducer exhibits a resolution to sinusoidal length changes on the order of 20 μm [10] with linear output at small displacements, known as short-range stiffness. With large displacements, the transducer stiffens, exhibiting decreased sensitivity [10]. Our design goal is a transducer with similar resolution and a large linear region, stiffening to lower sensitivity output at the end of its range. The final role, encoding, translates the analog depolarization of the transduction sites into a frequency-modulated spike train with a range of approximately 0–400 Hz. Our goal is to create an encoder that also produces a frequency-modulated spike train proportional to the analog voltage of the transducer.

Design documentation, including mechanical drawings and parts lists for hardware used in the robotic muscle spindle, can be found at http://brl.ee.washington.edu/.

B. Implementation

1) Mechanical Filter: The mechanical filtering task is implemented with a low-inertia, direct-drive lead screw linear actuator system, shown in Fig. 3, to achieve the rapid response times of the intrafusal muscle. A miniature ironless core dc motor (1016-N-006, MicroMo, Clearwater, FL) is coupled to a cold rolled stainless steel 2-56 lead screw with a flexible helical coupling. The system is mounted between a pair of semicylindrical stainless steel guides with a Delrin AF bushing aligning the tip of the lead screw and the guides.

The transducer element is mounted on a platform machined from Delrin AF with a 2-56 thread tapped through its center. This platform has integral linear bushings which ride in the track formed between the two semicylindrical housings, allowing the lead-screw

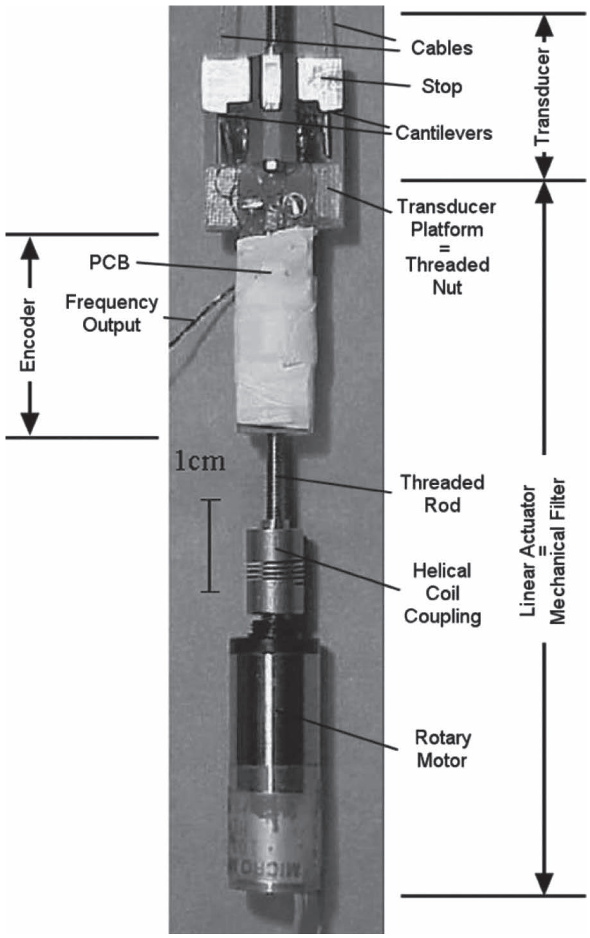

Fig. 3. Linear actuator and transducer assembly.

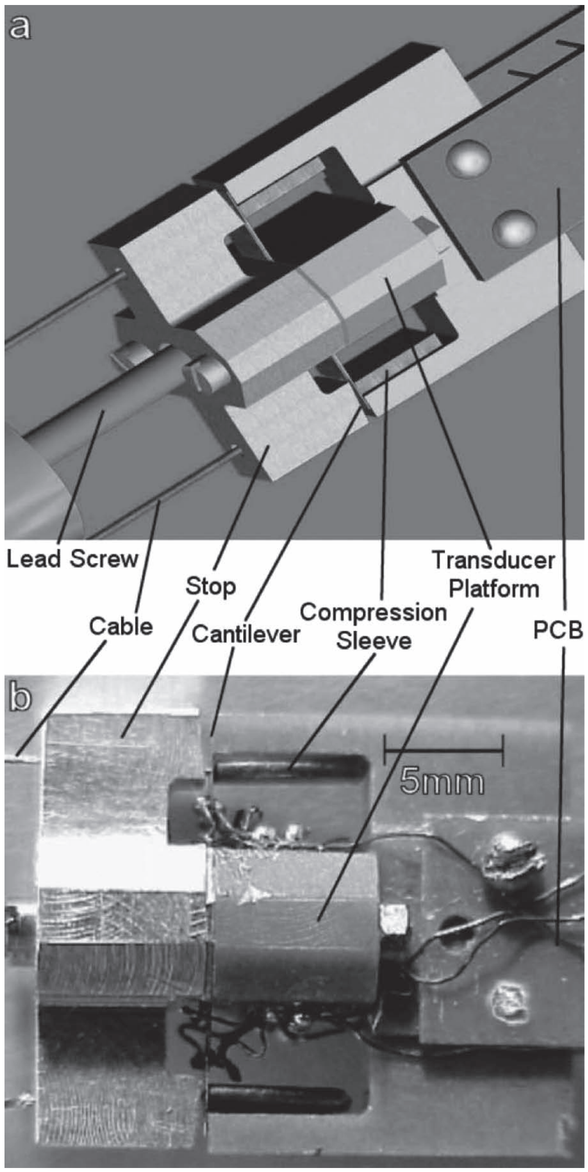

Fig. 4. Transducer platform. Consists of Delrin AF bushing and aluminum stop. Strain-gauged transducer is visible in the gap between bushing and stop. (a) CAD drawing. (b) Photograph of hardware.

rotation to be transformed into linear motion of the platform. Mounted onto the lead-screw system, the transducer platform forms the endpoint of the intrafusal muscle implementation, which lies in series with the transducer.

An encoder (HEM-1016-N-10, MicroMo, Clearwater, FL) is mounted directly to the motor. Its quadrature signal is read by a dSPACE 1102 controller board (dSPACE GmbH, Paderborn, Germany). The encoder data are filtered with a 25-Hz fourth-order digital elliptic filter. A proportional-integral-derivative (PID) controller for the complete linear actuator was designed in MATLAB and Simulink, then implemented in C (Real Time Workshop, MathWorks, Natick, MA).

2) Transducer: The transduction element, shown in Fig. 4(a) and (b), lies in series between the linear actuator and the distal end of the robotic muscle spindle. We implemented high-resolution transduction between strain and analog voltage with a pair of strain-gauged cantilevers mounted perpendicular to the axis of sensing.

The cantilevers are machined from stainless steel shim stock 51 μm thick. An aluminum stop 0.16 mm above the plane of the cantilever, machined to a 6.6° angle, is used to keep the cantilever's deflection within its linear elastic range.

One uniaxial polyimide and constantan alloy self-temperature-compensated 120-Ω strain gauge (EA 06031 CF 120, Measurements Group, Raleigh, NC) is mounted to the bottom surface of each cantilever. The dimensions and materials of the cantilever were selected such that a maximum of +2000/ − 0 μ strain

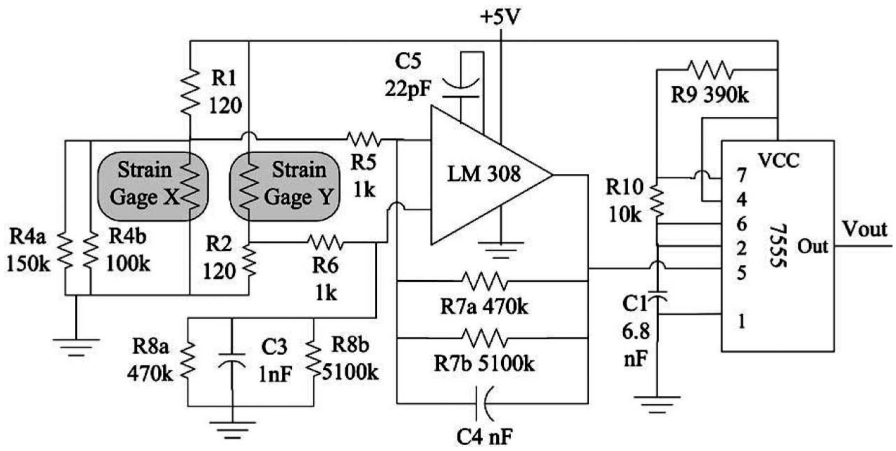

Fig. 5. Encoder circuit diagram. Strain sensed by strain gauges generates a millivolt potential across a Wheatstone bridge. That signal is amplified (LM 308 chip), then converted (7555 chip) to a frequency-modulated square wave.

would be applied to the foil matrix of the strain gauges during deflection, giving a fatigue life of 10^8 cycles.

Input displacements are applied to the cantilevers by means of nylon-coated 3 × 7 stainless steel cables. These cables run through guide holes both in the Delrin AF bushing at the distal end of the position sensor, as well as in the aluminum stop immediately adjacent to the cantilevers to ensure robust and repeatable performance, unmarred by tangling of the cables in the lead screw. The tension of the cables is transmitted to the cantilever by means of steel compression sleeves crimped to form a solid beam. The beam runs the width of the cantilever, thereby minimizing edge effects on the strain gauge film.

3) Encoder: The encoding of the analog voltage into a frequency-modulated spike train is implemented with surface-mount integrated circuit (IC) chips on a printed circuit board mounted directly to the sensor platform. The circuit, shown in Fig. 5, uses a Wheatstone bridge configured as a half bridge and is zeroed by a 60-kΩ resistor in parallel with one of the 120-Ω bridge completion resistors. The resulting signal is then immediately amplified with a gain of 430. The amplified signal is then sent into a 7555 IC, wired-in voltage-controlled oscillator mode, resulting in a frequency-modulated square wave with a range of 1150–12 500 Hz.

C. Linear Positioning Device

We designed and built a linear positioning device (LPD), shown in Fig. 6, to provide position inputs to the robotic spindle. The actuator was based around a 5.25-in hard-drive actuator. The rotary displacement of the precision hard-drive motor was converted to linear displacement by wrapping a metal ribbon 3.17 mm wide and 0.10 mm thick around a metal drum rigidly mounted to the motor. A slot machined in the outer circumference of the drum aligns the metal ribbon with the linear axis. The metal ribbon is then rigidly mounted to the ball slide of a miniature linear guide. The motion of this ball slide is defined as the linear position output of the actuator.

To control the actuator's position, we use an LVDT (LD100-20, Omega, Stamford, CT) rigidly mounted to the LPD base such that its axis is parallel to the linear slide rail. The aluminum core of the LVDT is then rigidly

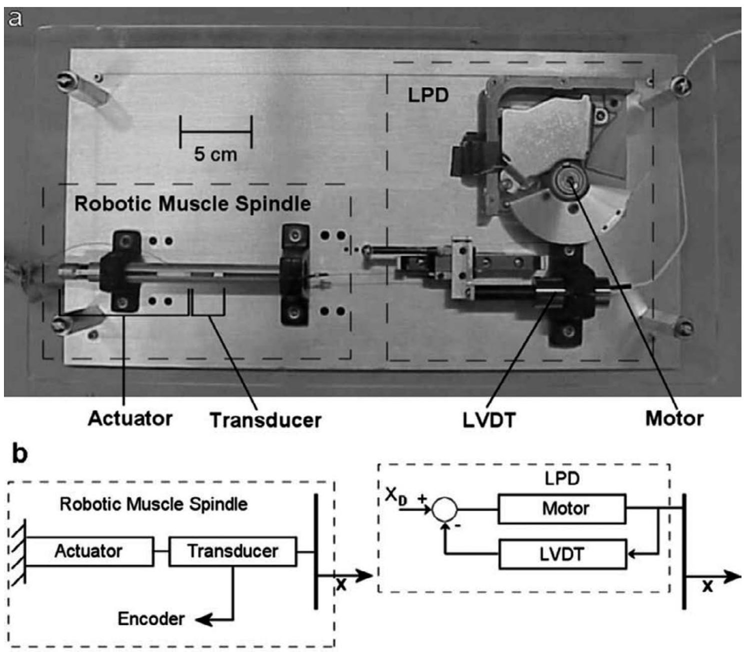

Fig. 6. LPD and robotic muscle spindle. (a) Photograph of device. (b) Schematic of robotic muscle spindle and LPD hardware.

fixed to the ball slide. The data are filtered with a third-order 40-Hz Butterworth filter. A separate PID controller was designed for the LPD and implemented in the same dSPACE system.

To perform experiments on the robotic spindle, the cable from the robotic muscle spindle is fixed directly to the ball slide of the LPD.

D. Modeling

1) Mechanical Filtering: The transfer function for position control of the linear actuator is

$$\frac{X_A(s)}{V_{IN}(s)} = \frac{K_m P}{JLs^3 + (RJ + LB)s^2 + (RB + K_b K_m)s} \tag{1}$$

where J = inertia, L = motor inductance, R = motor resistance, B = damping, K_b = back electromotive force (EMF) constant, K_m = torque constant, P = thread pitch, X_A = linear actuator position, and V_{IN} = motor voltage. With the parameter values for our system inserted, the transfer function for position control of the linear actuator is

$$\frac{X_A(s)}{V_{IN}(s)} = \frac{217}{2.4*10^{-6}s^3 + 0.74s^2 + 10s}\,\text{mm/V}. \tag{2}$$

Our desired step response was Tr < 30 ms, Ts < 150 ms, P.O. = 10%, and Ess = 0. A PID controller was designed iteratively, both in simulation and on the physical hardware, to meet these specifications. The resulting controller gains are K_P = 100, K_I = 10, and K_D = 0.5. This design gives the following theoretical step response: Tr = 3.5 ms, Ts = 18 ms, P.O. = 25%, and Ess = 0.

2) Transducer: We derived the linear relationship between displacement of the transducer element, x_C, and the strain of the strain gauges, ε, to be

$$\varepsilon = \frac{3C_{\text{th}}(L-d)}{2L^3}x_C \tag{3}$$

where C_{th} = cantilever thickness, L = distance from cantilever base to load, and d = distance from cantilever base to center of strain gauge. See the Appendix for the derivation of (3).

We designed the transducer with values for L, d, and C_{th} such that the displacement range, x_C, yielded the desired 2000-μ strain at full-scale deflection. As this transducer is analog, it has continuous resolution. Hence, the resolution goals were met. Finally, this model shows the response is linear throughout the transducer's primary range.

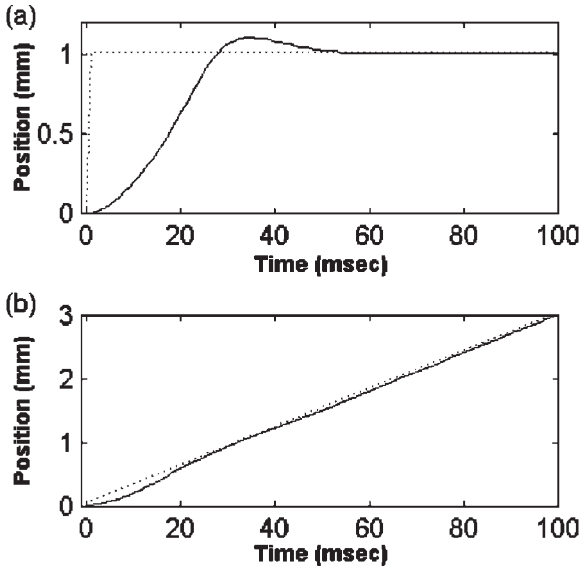

Fig. 7. Time response of linear actuator implementation of intrafusal muscle (solid line). (a) 1-mm step position input (dotted line). (b) 30-mm/s ramp position input (dotted line).

3) Encoder: Accounting for the electrical and mechanical properties of the strain gauges and the pulse generation circuit, we derived the relationship between strain ε and frequency F as

$$F = \left[.69R_BC + (R_B + R_C)C\ln\left[\frac{\frac{5R_2}{2R_1}\left(\frac{\varepsilon G}{2+\varepsilon G}\right) - 5}{\frac{5R_2}{R_1}\left(\frac{\varepsilon G}{2+\varepsilon G}\right) - 5}\right]\right]^{-1} \tag{4}$$

where R_B = resistor between 7555 V_{CC} and discharge pins, R_C = resistor between 7555 discharge and threshold pins, C = capacitor across 7555 trigger and ground pins, R_2/R_1 = amplifier gain, and G = gauge factor of strain gages. See the Appendix for the derivation of (4).

Values for these parameters were selected to give a large frequency range of approximately 1–14 kHz to maximize resolution.

III. Results

A. Actuator Performance

Fig. 7(a) shows the step response of the linear actuator. The performance metrics for this step function are Tr = 26 ms, Ts = 54 ms, P.O. = 9.2%, and Ess = 6.8 × 10^{-3} mm, which meets our goal of Tr < 30 ms, Ts < 150 ms, P.O. 10%, and Ess ~ 0.

On a 30-mm/s ramp trajectory [Fig. 7(b)], the performance metrics are P.O. = 0.36% of absolute position, overshoot = 0.089 mm, maximum error = 0.15 mm, and mean absolute Ess = 0.041 mm.

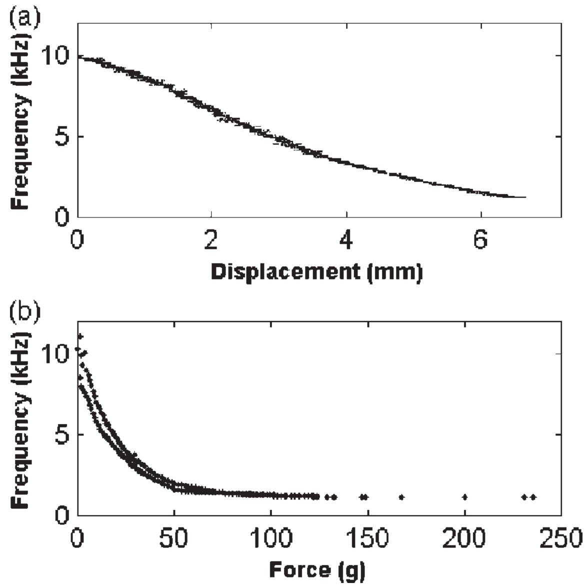

Fig. 8. Calibration plots for transducer. (a) Frequency versus displacement. (b) Frequency versus force.

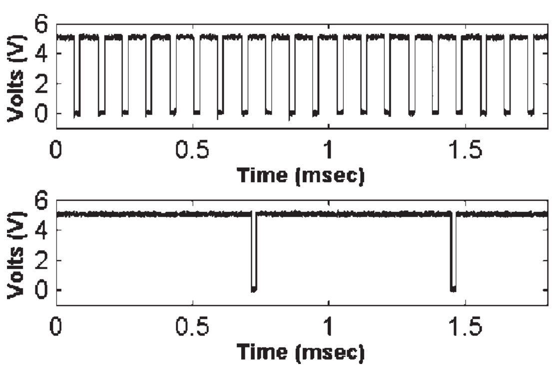

Fig. 9. Waveform of frequency-modulated square wave. (top) Small sensor displacement. (bottom) Large sensor displacement.

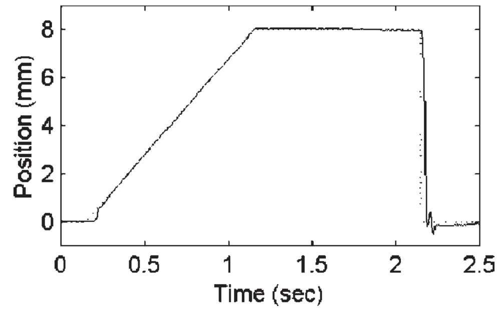

Fig. 10. Time response of LPD (solid line) to 6-mm/s ramp and hold position input (dotted line).

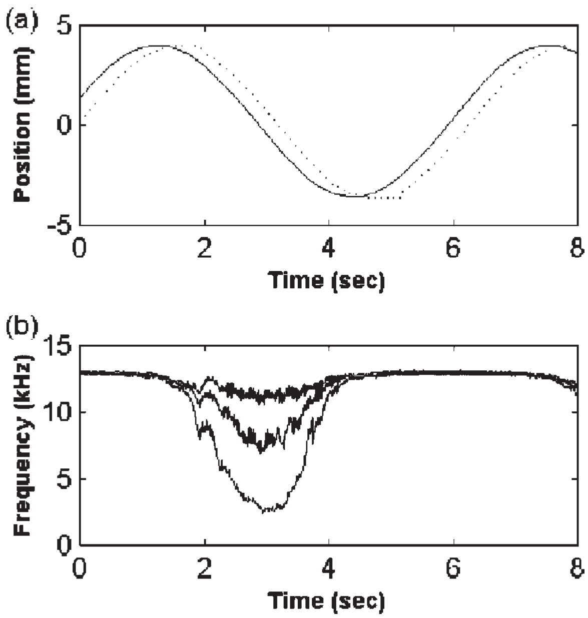

Fig. 11. Test of integrated engineering hardware using position control. (a) Trajectory of robotic sensor (solid line) and LPD (dotted line) for phase lead of 20°. (b) Frequency output for phase leads of 8.6°, 14.3°, and 20.0°.

B. Transducer and Encoder Calibration

Fig. 8 shows the combined calibration of the transducer and encoder systems. Calibration is depicted between displacement and frequency, shown in Fig. 8(a), and force and frequency, shown in Fig. 8(b). In each, the response is linear at small-to-moderate displacements and forces, followed by a region at the end of the range exhibiting decreased sensitivity, reflecting the design specifications. The displacement versus frequency plot, Fig. 8(a), is highly repeatable over a wide range of velocities, reflecting the absence of velocity dependence in the transducer and encoder subsystem. Fig. 9 demonstrates the waveform generated by the encoder circuitry at both the low and high ends of the encoder's working range. The observed range of strain across the strain gauges is 66–1700 μ strain, within the targeted 0–2000 μ strain range.

C. LPD Performance

Fig. 10 shows the ramp response of the LPD during a 6-mm/s ramp and hold. For PID controller values of P = 10, I = 140, and D = 0.1, the 6-mm/s ramp performance metrics are P.O. = 0.75%, overshoot = 0.017 mm, and mean absolute Ess = 0.018 mm.

D. Integrated Performance

To initially test the performance of the three core elements as an integrated system, we implemented a simple position controller for the linear actuator, and programmed both it and the LPD testing machine to move with the same sinusoidal trajectory, separated only by a phase lead. The resulting performance is shown in Fig. 11.

As is shown in Fig. 11, the transducer produces a response proportional to the "error" in the host muscle's

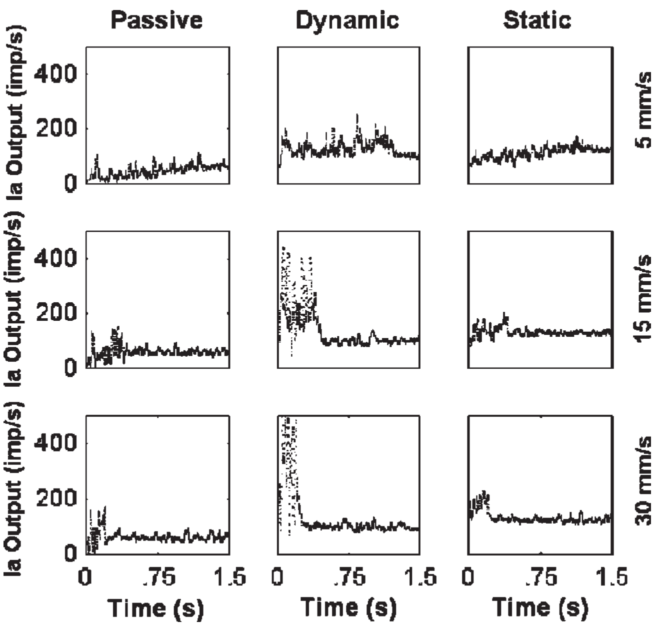

Fig. 12. Effect of ramp speed and γ mn input during 6-mm amplitude ramp and hold on Ia response of integrated system under physiologically based control. Left column: no γ mn input (passive). Middle column: 100 Hz dynamic, 0 Hz static (dynamic). Right column: 0 Hz dynamic, 100 Hz static (static).

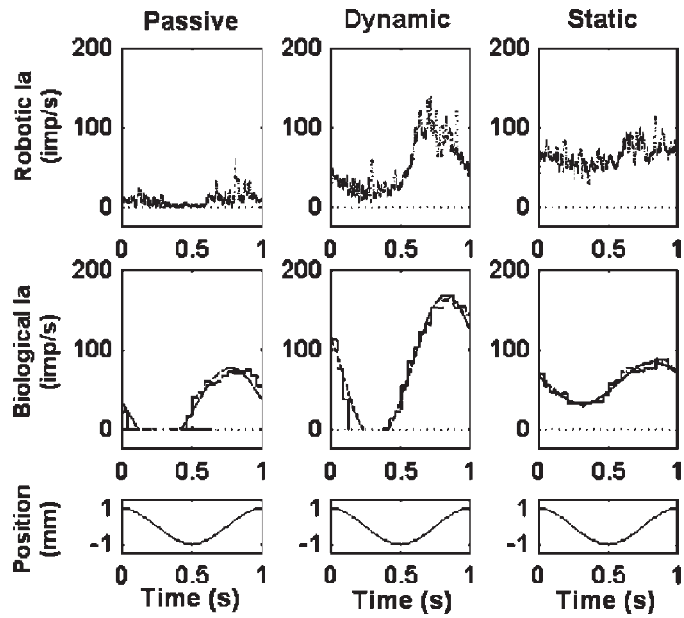

Fig. 13. Comparison of integrated system response to biological muscle spindle response (c.f. Hulliger *et al.* 1977 [16]). Robotic response (top row) matches phase lead and shape, but not amplitude, of cat soleus muscle spindle response (middle row) to sinusoidal position input (bottom row) under different γ mn levels. Left column: no γ mn input. Center column: 87 Hz dynamic. Right column: 100 Hz static.

displacement, as created by the phase lead of the robotic sensor's movement. Like the biological spindle, it only detects stretching, and not compression, forces. Additionally, the frequency response reflects any transient perturbations between the robotic sensor's motion and the host muscle's motion. An example of this is the local peaks produced at 1.95 s when the LPD experiences stiction and briefly deviates from the sinusoidal trajectory.

Figs. 12 and 13 show the performance of the hardware elements following full integration and validation with a physiologically based controller. In this force control algorithm, the force across the actuator is controlled by an intrafusal muscle model, in which the desired force across the actuator is calculated as a function of actuator length, velocity, and γ mn input rate. Whole muscle spindle output (Ia) is calculated as a function of transducer displacement and its first derivative. Integration, tuning, and validation details are described elsewhere [1], [11]. Fig. 12 shows that the response of the robotic system to variation in ramp velocities and γ motorneuron (γ mn) activation levels is well tuned to match the current theory regarding muscle spindle behavior. Position gain (i.e., position sensitivity) is independent of speed, but dependent on a γ mn activation level, which alters the properties of the linear actuator's control algorithm. The muscle spindle's characteristic high position gain at small displacement is exhibited in the spikes at ramp onset [12]. The velocity gain (i.e., velocity sensitivity) produces a speed-dependent offset during the ramps, which is dependent on a γ mn activation level. The noise exhibited is normally distributed with a standard deviation of 10.5 Hz, which is typical of active biological muscle spindles, which exhibit normally distributed noise with a standard deviation of ~ 8 Hz [13]. The model's time-do-main sinusoidal response, Fig. 13, shows good qualitative correspondence to the biological response, including similarities in phase lead and relative amplitudes under different γ mn levels. In the passive case, response amplitude varies from the biological data, revealing a limitation of the device. Noise is absent in the biological cases, because these data are the average response of multiple trials.

IV. Discussion

This paper presents a physically realized robotic implementation of a biological length and velocity sensor, the mammalian muscle spindle. We set out two hypotheses in this paper. First, that a sensor that captured the three core behaviors of mechanical filtering, transduction, and encoding could exhibit the type of behavior seen in muscle spindles. Second, that the electromechanical devices we selected to implement each of these core functions could meet the performance specifications necessary to express each of these behaviors.

Each of the three electromechanical subsystems met the required performance specifications to replicate their biological analogs. The linear actuator met the desired time-response criteria, demonstrating it is fast enough to replicate the mechanical filtering behavior of intrafusal muscle. The transducer detected displacements with the desired resolution and linearity. For the encoder subsystem, we did meet our desired frequency range, although we had intentionally chosen a range substantially different from the biological encoder range. There were two reasons for selecting a different frequency range. First of all, we desired a frequency range of several kilohertz, whereas the biological encoder range is approximately 0–400 Hz. This increase in range is a consequence of needing to increase resolution beyond that of biological muscle spindles. This was necessary because our sensor will be used in a 1:1 ratio with the host muscle, while biological muscle spindles are often found in much higher densities, e.g., approximately 53–56 muscle spindles in the cat soleus muscle [14]. Secondly, our displacement-frequency relationship is the inverse of the biological spindle's relationship. In our system, increasing displacements lead to decreasing frequencies. This choice was made to minimize the number of IC chips in the pulse generation circuitry. This, in turn, allowed the circuit to be mounted directly to the transducer platform. Based on the fact that all three subsystems met the performance specifications of their biological analog, the second hypothesis was confirmed.

The results from our tests of the integrated system support the first hypothesis as well, which states that a robotic sensor which captures the muscle spindle's core functions (mechanical filtering, transduction, and encoding) can exhibit the type of response seen in muscle spindles. When the three elements are integrated using a simple position controller, they produce an output proportional to the positive displacement discrepancy between the actuator and the LPD, as seen in biological muscle spindles. Further, they detect this equally well during low-frequency sinusoids and transient perturbations. When integrated using a physiologically based controller, the system is able to replicate the major features of the performance of the full mammalian muscle spindle. Hence, we have shown that the first hypothesis is correct, these three hardware subsystems are capable of exhibiting the type of sensing behavior seen in muscle spindles.

In conclusion, using mechatronic hardware, we have created a sensor which replicates the transducer behavior of a biological length and velocity sensor, the muscle spindle. Such a device has applications in basic science, as a testbed for studying motor control, and in prosthetics, as a sensor which communicates in the language of the user's motor control system. The question remains, though, as to the suitability of such a device for engineering applications. An actuated sensor, i.e., a sensor which possesses an internal actuator whose sole function is to serve as a filter between the sensor's input and output, is not commonly employed for kinematic measurements in engineering applications. We propose that such a system might be advantageous in situations where the range of the actual transducer is limited, or for real-time tuning of the sensor's output to a variety of different kinematic variables, e.g., length, velocity, or perturbations from a desired length.

Appendix

A. Relationship Between Cable Displacement x_C and Cantilever Strain ε

The deflection of a cantilever, x_C is defined as [15]

$$x_c = \frac{PL^3}{3EI} \tag{5}$$

where P is force applied by the cable, E is the cantilever modulus of elasticity, and I is the cantilever's moment of inertia. Given a cantilever constant rectangular cross section, the strain, ε, at point a, the center of the strain gauge, is defined as [15]

$$\varepsilon \frac{P(L-d)C_{\text{th}}}{2EI}. \tag{6}$$

Using A.1 and A.2 gives

$$\varepsilon = \frac{3C_{\text{th}}(l-d)}{2L^3}x_c.$$

B. Relationsip Between Cantilever Strain ε and Voltage-Controlled Oscillator Frequency F

The circuit shown in Fig. 5 uses a Wheatstone bridge configured as a half bridge to transduce cantilever strain to an analog millivolt potential. This millivolt output is then immediately amplified by the LM308 op amp to give the following:

$$V_{\text{control}} = \frac{R_1}{R_2}\left(\frac{\varepsilon G}{2+\varepsilon G}\right) \tag{7}$$

where R_1/R_2 is the amplification due to the LM308, and εG is the change in strain-gauge resistance due to cantilever strain. V_{control} is then the voltage-controlled oscillator input for a 7555 timer chip wired for a stable oscillator mode. In this mode, the capacitor C is charged and discharged between V_{control} and $V_{\text{control}}/2$. The time required for the capacitor to charge is

$$t_{\text{charge}} = (R_B + R_C)C\ln\left[\frac{V_{\text{control}} - 5}{0.5V_{\text{control}} - 5}\right]^{-1}. \tag{8}$$

The time required for the RC circuit to discharge by 50% across R_B is

$$t_{\text{dissipate}} = 0.693R_B C. \tag{9}$$

Using A.5 and A.6, the frequency of a 555 timer in a stable oscillator mode is given by

$$F = \left[0.693R_B C + (R_B + R_C)CIn\left[\frac{0.5V_{\text{control}} - 5}{V_{\text{control}} - 5}\right]\right]^{-1}. \tag{10}$$

Combining A.7 and A.4 gives the relationship between strain ε and frequency F

$$F = \left[.69R_B C + (R_B + R_C)CIn\left[\frac{\frac{5R_2}{2R_1}\left(\frac{\varepsilon G}{2+\varepsilon G}\right) - 5}{\frac{5R_2}{R_1}\left(\frac{\varepsilon G}{2+\varepsilon G}\right) - 5}\right]\right]^{-1}.$$

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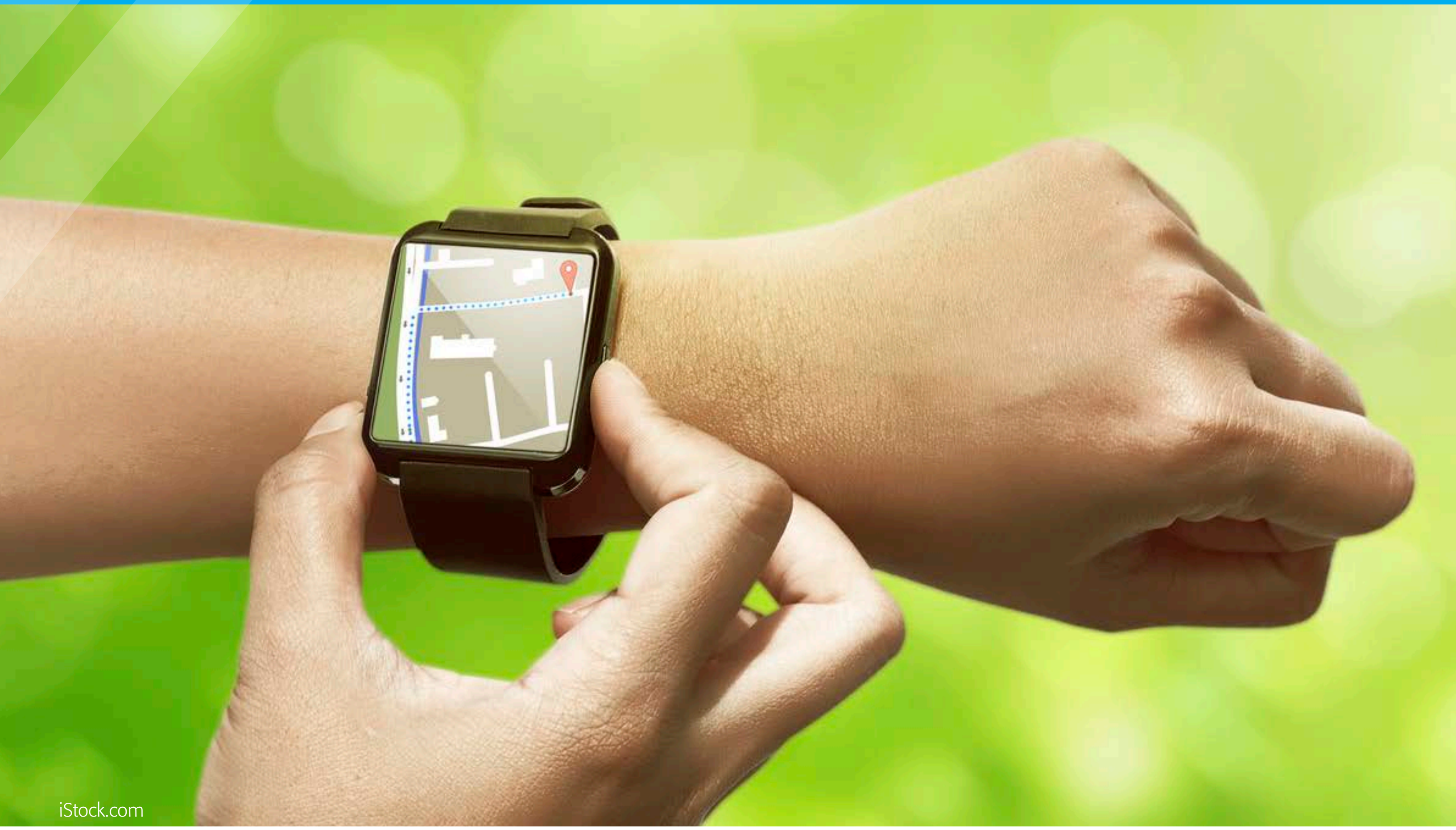

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Unconventional Biosignal Sensing with Passive RFID Tags

by: Shrenik Vora (Beta Alpha Chapter) and Timothy P. Kurzweg (Epsilon Chapter)

Abstract:
Wireless wearable devices have become ubiquitous in both clinical settings and personal health monitoring. Availability of compact, low-power electronic components has made continuous monitoring of many health parameters possible. However, monitors can be further improved by making them battery free and reducing the data processing on the sensor side before data transmission. Passive RFID tags can be advantageous in wearable monitoring applications, as they do not need a local power source for transmitting data. In this article, a passive RFID-based bioelectric signal sensor and strain gauge are discussed as methods to detect and transmit health parameters without the need for batteries.

I. Introduction

In the past few years, we have witnessed tremendous growth in the wearable health monitoring industry. Monitoring devices have become smaller and unobtrusive, which has made continuous monitoring feasible. Batteries and electronics have become more compact and efficient, thereby reducing their footprint and allowing for reasonable usage between re-charges. The monitoring devices interface easily with handheld devices that have internet connectivity, allowing for remote monitoring and on-demand data access. A number of health parameters, including heart rate, respiration rate, sleeping patterns, hydration, and step counts can simultaneously be monitored with minimal interruption. Extensive research in the field has led to the development of multiple methods of sensing and transmitting biosignals. In spite of the diversity in the electronics used for sensing the biosignal and the communication platform employed in transmitting it, almost all wireless wearable monitors have the same building blocks. A typical wearable device goes through the following steps to achieve monitoring:

- Sensing: The biosignal of interest is detected and proportional electrical response is produced
- Amplification: The electrical response generated by the sensing component is typically too small for analysis and usually needs to be amplified
- Digitization and Storage: The amplified biosignal is digitized with an analog to digital converter and then stored to a memory device
- Data Transmission: The stored data is transmitted over a wireless communication platform like Bluetooth

With the availability of small foot-print, ultra-low power microprocessors and other energy efficient electronic components, the sensing, amplification and digitization steps can be optimized. Low energy communication protocols have further reduced the power requirements for wirelessly transmitting monitored biosignals. These energy savings have allowed the batteries to become smaller, while enabling prolonged continuous monitoring on a single charge. To date, the growth in the wearable devices field has mainly been fueled by reducing component size and power requirements for each of the above steps. However, what if these steps could be combined or entirely bypassed? The reduction in system size and power consumption could be large, enabling devices to become even more wearable.

Another issue with contemporary wearable devices is the necessity to have batteries for operation. These batteries need to be periodically replaced or recharged, creating the need to provide access ports for batteries. The necessity of these access ports prevents seamless integration with wearable platforms, which may consist of garments or commonly worn accessories. Without these battery access ports, wearable monitoring could be seamlessly integrated with clothing for continuous unobtrusive monitoring.

In this article, some novel methods that employ passive RFID (Radio Frequency Identification) technology to reduce the steps involved in biosignal monitoring and eliminating the need for local batteries are discussed.

II. Passive UHF RFID Technology

RFID systems are categorized by frequencies into three broad categories: Low Frequency (135kHz), High Frequency (13.56MHz), and Ultra High Frequency (868/915 MHz/2.5GHz/5.8GHz). Of these, the UHF tags have the highest range, which is of the order of tens of feet. UHF RFID tags can either be ‘active’ or ‘passive’; wherein the later are a category of tags that do not need any local batteries for operation. A typical passive UHF RFID system is shown in Figure 1. The picture depicts an RFID reader and a passive tag. The RFID reader sends a radio frequency (RF) interrogation signal, which is received by the tag. The tag is powered wirelessly by this interrogating RF signal, then uses this energy to backscatter its unique tag ID. Backscatter communication is conducted by varying the load seen by the tag antenna with the data to be transmitted. The tag achieves this by changing its impedance between a high and a low impedance state, wherein each state corresponds to a ‘0’ or a ‘1’. Such an RFID communication platform does not require any local power source for data transmission, which makes this technology particularly promising for

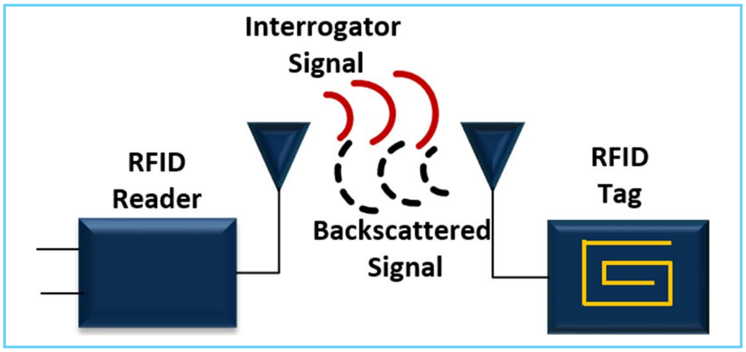

Figure 1 Passive Ultra High Frequency (UHF) RFID System

biosignal data transmission. Therefore, with passive RFID, biosignal data can be transmitted without using any sensor battery power, thereby allowing significant reduction in power and size for a wearable monitor.

RFID-based sensor systems have been employed to create battery- free electroencephalogram (EEG) and electrocardiogram (ECG) monitors [1,2]. These systems transmit entire bioelectric signal waveforms after following the process of sensing, amplification, digitization and storage. The power required to transmit the entire signal limits such sensors' range considerably. For acquiring health parameters like heart rate and respiration rate, entire signals need not be transmitted. Features of the RFID communication platform can be leveraged to unconventionally sense and transmit these parameters with minimal local power. In the next section, we will present some of the passive RFID sensor research being performed at Drexel University.

III. Novel Passive RFID Sensors

A. RFID Bio-Electric Signal Sensor

RFID tags are conventionally used in electronic article surveillance (EAS) systems where communication between the RFID reader and tag is mainly significant at the instant when the tag enters the reader's interrogation field. Once the article's presence has been detected, repeated reads of the article are redundant. However, one can continuously interrogate an RFID tag as long as it stays within the reader's field and each new read carries new sensor data.

One simple way of transmitting sensed data with continuous RFID tag reads is shown in Figure 2. In this example, an ECG wave is used as a biosignal source to monitor heart rate. In the absence of any disruptions, the RFID reader receives responses from the tag at regular intervals (shown as blue stars in Figure. 2). This communication channel between the reader and the tag can be momentarily broken every time an ECG pulse ('R' wave) is detected. This 'turning off' of an RFID tag would create a temporary RFID outage (as shown by the gap between yellow vertical bars in Figure 2). Thus, each RFID outage corresponds to the detection of a heartbeat; the RFID reader can easily detect these outages. Using the RFID in this way creates data transmission using a simple OOK (on-off-keying) coding. By finding the time between successive RFID outages, the heart rate can be calculated. In this fashion, heart rate information can be transmitted without the need to store data locally.

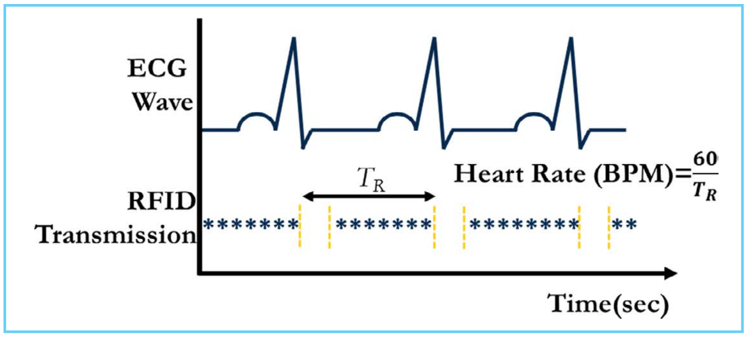

Figure 2 Operating Principle of RFID Bio-Electric Signal Sensor

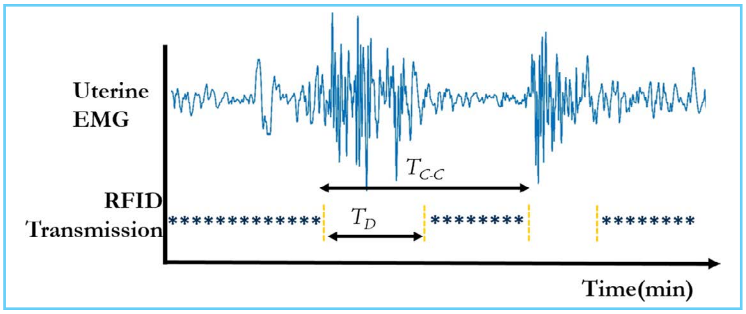

Figure 3 RFID bioelectric signal sensing of uterine contractions (T_D: Duration of contraction, $T_{C\text{-}C}$: Time between contractions, sample EHG data obtained from [4,5])

The RFID communication channel serves the dual purpose of data digitization and transmission. By using this method, extra circuitry for data digitization, storage and transmission can be avoided, thereby reducing system size and power requirements. Additionally, the power required to operate the ECG amplifier and beat detection circuit can be harvested wirelessly from the RFID reader's interrogation signal, thereby eliminating the need for batteries. Such an RFID system has been shown to work for a range of over twelve feet and a heart rate detection range of 30 to 300 beats per minute without batteries or any other local power source [3]. It is possible to use this system to monitor multiple people simultaneously as the RFID tag acts as a unique identifier, and outages in each tag can be correlated to a specific person's heart rate.

Though the previous example has been shown for heart rate, other bio-parameters can also be determined using this OOK RFID method. A RFID tag can be turned on and off based on the detection of pulses within bio-electric signals. Figure 3 shows the bioelectric signal that represents contractions experienced by pregnant women, called an electrohysterograph, or simply uterine EMG (electromyography). Here, the RFID tag is turned off for the duration of the contraction. Thus, the outage

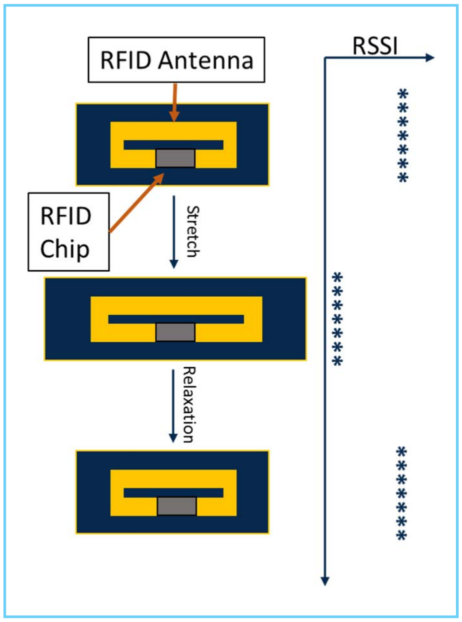

Figure 4 Operating principle of RFID strain gauge

duration conveys the contraction time, and time between outages conveys the frequency of contractions. Such a system can be used to create an at-home wearable contraction monitor for pregnant women.

B. RFID Strain Gauge

The backscatter communication from the RFID tag, described earlier, is dependent on the tag antenna geometry, among other parameters. Hence, the strength of the RF signal backscattered by the RFID tag can be altered by changing the dimensions of the tag antenna. Received Signal Strength Indicator (RSSI) is a feature used to measure the strength of the signal backscatter by the tag. By slightly deforming the tag antenna, the RSSI value measured by the reader changes. If the tag antenna were to deform due to a physical activity, that activity could be monitored by recording the change in the RSSI values. This principle is demonstrated in Figure 4. While the RFID tag antenna is relaxed, it has a certain RSSI value associated with that state. When the tag is stretched, the tag antenna changes its dimensions, and the RSSI values measured also change. In this case, sensing and data transmission are both done by passive RFID tags while digitization is moved off the sensor.

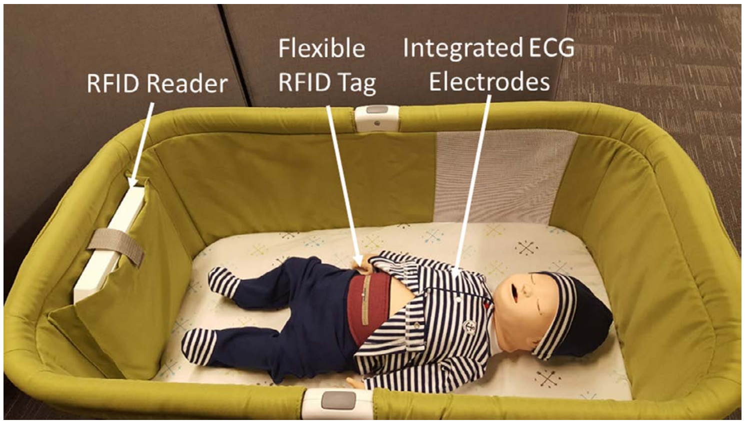

Figure 5 Passive RFID-based heart and respiration rate monitoring for infants (Image courtesy William Mongan, Drexel University)

Strain-based biosignal measurements are possible with tags that allow for change in backscatter signal based on deformations. For example, such a flexible antenna could be used to measure uterine contractions as well. The tag and antenna could be placed on a pregnant woman's belly. The tag would then stretch and relax due to the contractions, and the recorded RSSI values would change. The change in the recorded RSSI can then be correlated to the duration and frequency of uterine contractions. A tag based on this principle has been fabricated using antennas knitted on garments using conductive thread and inductively coupled RFID chips [6].

IV. Use Case: RFID Infant Heart and Respiration Rate Monitor

Physicians and parents are often interested in monitoring an infant's heart and respiration rate as an indicator of the baby's well-being and health. Wearable monitoring for babies presents added challenges, in that comfort, size and seamless integration are of utmost importance. The RFID bioelectric and strain sensors can be combined to create a minimal footprint infant heart and respiration monitoring system without any batteries [7]. A vision for such a system is shown in Figure 5. The RFID reader is placed within the crib to communicate with the sensor RFID tags. The baby has a fabric RFID tag around the belly to record his/her respiration rate. As the baby breathes in and out, the fabric RFID tag stretches and relaxes to vary the RSSI values measured. Fabric ECG electrodes can be integrated into the baby's garments to sense the ECG signal and turn the RFID tag on and off based on the detection of a heartbeat. The baby can thus be monitored continuously with no discomfort and with minimal on-body sensing electronics.

V. Conclusion

The future growth in wireless wearable monitors lies in reducing size and power by employing novel reductions in local data processing and electronic components.

Passive RFID systems work entirely on power harvested wirelessly from a reader and do not require local batteries. These features of passive RFID systems can be leveraged to make sensors that rethink the conventional steps of sensing, amplifying, digitizing and transmitting biosignal data. The sensors discussed here, of course, suffer from the limitation that they cannot operate in absence of an RFID reader in range. However, there are many cases where this limitation is not an issue. For instance, the required RFID reading infrastructure can be deployed in homes or hospitals in which the person being monitored moves in limited space.

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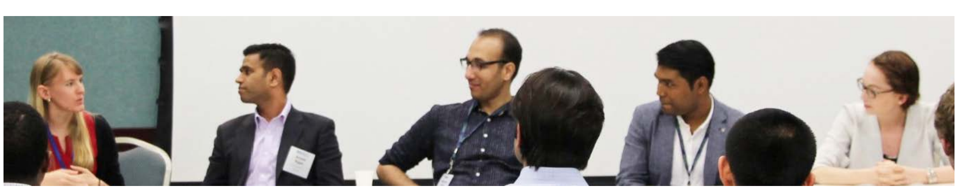

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Supavadee is Associate Professor, Department of Electrical Engineering at Chulalongkorn University. She formed the first IEEE-HKN Chapter (Mu Theta) in Thailand this year at her University, and serves as its Faculty Advisor. She is currently Educational Activities Coordinator of the IEEE Region 10 Executive Committee, and is a member of EPICS in IEEE, IEEE EAB's Section Educational Outreach Committee (SEOC), and IEEE-HKN's Globalization Committee and Region 10 Task Force. She is a member of IEEE Circuits and Systems (CAS) Society Technical Committee on Multimedia System and Applications; IEEE Communication Society Multimedia Communication Committee; and Chair of the IEEE Signal Processing Society Chapter, Thailand Section. Supavadee is Chair for APSIPA Image, Video, and Multimedia Technical Committee; IEICE Bangkok Section Chair; Associate Editor of IEICE Transactions on Information and Systems; and also serves as General Co-Chair of many well-known committees and conferences.

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

I chose Computer Science as my undergraduate field of study because I am fascinated by technological development. I still remember my senior project on Information "Retrieval on Thai Text" developed on the Windows 3.0 platform -- at the very beginning of what we know today as the World Wide Web. During my graduate study, I shifted to Electrical Engineering to focus on network simulation software during my master's and doctoral programs on wireless video transmission.

The engineering field not only inspires me to always adopt new technology tools to build new solutions to solve problems, but also enables me to contribute in several ways to my community and society...I like the opportunity to make a difference.

What do you love about the industry?

During my 15 years at Chulalongkorn University, I've had many opportunities to interact and collaborate with industry. Industry has the experiences of technology outcomes that have been put into practice. Collaboration between university and industry is considered very important -- such that the invention of new technology/solutions could develop into commercial uses, as well as practical experiences for students.

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

Professionally, the people I admire are senior colleagues at my University, Prof. Prasit Prapinmomgkolkarn and Dr. Teeranoot Chauksuvanit, who are also my best mentors. They both have significant career accomplishments and devote their attention to guide me to take the best course of action to further my career.

Personally, my family has always provided unconditional support. That support has given me freedom to choose the disciplines I want to pursue.

I began volunteering for IEEE in 2007. It was through my involvement, I met Prof. Takako Hashimoto, IEEE International Organizational Chair, Women in Engineering (WIE). Not only a colleague, she has become a good friend. I admire her for her career accomplishments, dedication to family, and significant contributions to IEEE -- especially the WIE community.

How has the engineering field changed since you entered it?

The evolution of the Internet has changed the engineering field and the way we work and interact with others. For example, with advanced video compression technology and the capability of high throughput wireless, accessibility of video to remote distances is possible and useful in the applications of interaction, health, learning, entertainment, and especially to help bridge the digital gap in society.

Supavadee with members of the Mu Theta Chapter at the Chapter's installation on 7 March 2016

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

Today, almost every piece of technology can be virtually connected anytime and anywhere. Technological convergence has started taking place. As several futurists predicted, the Internet will connect all pieces of "things" together -- "things" could be sensors, small wearable devices, cloud storage, robots, etc. Thus, engineers need to be well-rounded to work on multidisciplinary technologies; they will also need to consider societal impacts.

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

As an academician and a researcher, I view "collaboration" as the most important instrument in my work. The best lesson I have learned is that we accomplish more through collaboration. I consider myself as a networking, bridge-connecting, focal-pointed person. Being an IEEE Member expands both my technical and professional network significantly, and being IEEE-HKN opens the world to connect with distinguished professional colleagues. Collaboration can start at any point of time once we can establish good networking connections.

> Today, almost every piece of technology can be virtually con-nected anytime and anywhere.

What advice can you offer recent graduates entering the field?

Be bold and put effort into what you are working on. Set precise goals and go for it. Discover your ambition, work passionately, balance your work and personal life, and always be your best. Follow the IEEE-HKN motto…"to lead a balanced life, a life in which SCHOLARSHIP, CHARACTER, and ATTITUDE are jointly developed."

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

I would like to be a diplomat. It is my nature to collaborate… to build relationships and make connections. Even as a technician, I am a diplomat in my passion to bring people together to meet a shared goal or purpose.

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

I would spend more precious time with my family and loved ones. It is most important for me to spend time with those in my life who have given me so much and inspire me.

William Thomson – The Lord Kelvin

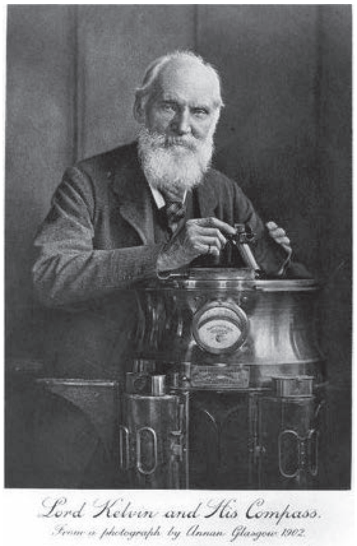
The unit for absolute temperature is named "kelvin" in honor of William Thomson, the first Lord Kelvin. This professor at the University of Glasgow, U.K., is known for diverse scientific and engineering contributions including developments toward the absolute temperature scale, as well as advancements in electricity theory and its applications. He began one of his noted lectures on "The Practical Applications of Electricity" with the following statement of his approach to understanding a technical subject:

> "…when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meager and unsatisfactory kind: it may be the beginning of knowledge, but you have scarcely, in your thoughts advanced to the stage of science." Lecture on "Electrical Units of Measurement" by William Thomson (Lord Kelvin) on 3 May 1883.

A review of his remarkable career was published in the proceedings of the American Institute of Electrical Engineering (one of the predecessors to IEEE) shortly after his death at the age of eight-three. This paper is freely available from IEEE Xplore: "Memoir of Lord Kelvin," Proceedings of the AIEE, Volume 27, Number 1, page 3-5, 1908.

Other details on his career are given at the Engineering and Technology History Wiki (supported by the IEEE History Center)

The figures below show Lord Kelvin with his compass and his mirror galvanometer. The later instrument made the transatlantic telegraph possible.



▲ Lord Kelvin. Image courtesy of Engineering and Technology History Wiki.

◀ Mirror galvanometer of Lord Kelvin used for detecting telegraph messages. Image licensed by The Science Museum of London under the CC 2.0.

Student Representative Column

by: Leann Krieger, Gamma Theta Chapter

Dear Members of IEEE-Eta Kappa Nu,

My name is Leann Krieger, and I am the 2016 Student Governor on IEEE-HKN's Board of Governors (BOG). As your representative, I would like to share with you my goals in this position, and challenge you to get involved in your organization!

The Student Governor position exists to help give students a voice. Students are one of the most important parts of HKN, so it is a great responsibility for me to listen to and address their concerns. In order to do this, I have three major goals:

1. Represent students and chapters on the Board of Governors
2. Facilitate communication between the Board of Governors and chapters
3. Facilitate communication between chapters

I have a vote on all strategic and tactical matters presented to the Board of Governors. Having attended meetings and worked with the Board, it is my observation that the person in this position needs input and feedback from our chapters and chapter leaders to both present ideas and solutions, and to review proposals. My suggestion is to create a Student Advisory Group. This group would consist of students (hopefully at least one from each region) who would give me feedback on topics they would like me to present at BOG meetings. This feedback will help me make a vote on actions decided by the BOG. I want to be able to represent the needs of each chapter in the best way possible, so your participation in this process is absolutely critical in order to share your ideas.

The main responsibilities of the Student Advisory Group would be to meet (via phone or video conference) once a month to discuss possible topics to be presented at upcoming meetings, as well as what priorities we feel may be necessary. We would also maintain contact through e-mail in order to share general news/updates from the BOG, and HKN in general.

I also hope to use the Student Advisory Group to bounce ideas off each other to help improve IEEE-HKN as a whole. This will give you a platform to network with other members and foster your communication and leadership skills. By serving on the Student Advisory Group, you will also have the opportunity to work on special projects -- such as planning and organizing the Student Leadership Conference or developing a chapter mentor program to help guide other young professionals.

If you are interested in joining the Student Advisory Group, or if you have any questions or concerns, please contact info@hkn.org (Attn: Leann Krieger) for more information. Remember that this is a great way for you to voice your opinions and suggestions, get involved with HKN at the Board level, consider running in the future for the Student Governor position, and perhaps even encourage you to be a future President of IEEE-HKN! We all take the same pledge -- this is our organization, let's make it everything we envision it can be. Your time is valuable; use it to invest in Eta Kappa Nu and your future. I need your support so we can make IEEE-HKN the best it can possibly be!

Student Representative Responsibilities:

- Attends and participates in all IEEE-HKN Board of Governors Meetings.
- Participates in the development of annual and strategic plans to support the mission of IEEE-HKN.
- Represents the interests of IEEE-HKN students and chapters
- Organizes and oversees ad hoc or other groups for the purpose or research, development, oversight, and implementation of benefits, programs, or services to best serve the needs of students and young professionals
- Serves on the IEEE MGA Student Activities Committee (SAC)

STUDENT PROFILE

Rafi Abdulla Koutoby, CAPM

Epsilon Theta Chapter

Born in New York City and raised in Dubai, United Arab Emirates, Rafi Koutoby is a Syrian-Filipino American who has been living in Southern California for seven years. After completing his secondary education in Dubai, graduating from Dubai Carmel School in 2008 with the International General Certificate for Secondary Education (IGCSE), and Dubai International High School in 2009, Rafi decided to return to the US for his university studies. He transferred from Golden West College in Huntington Beach and graduated in December 2015 from California State University, Long Beach (CSULB) with a Bachelor of Science in Electrical Engineering.

During his time at CSULB, Rafi was employed as a research assistant in a Raytheon-funded project profiling cryptographic encryption protocols on power-efficient wireless sensor networks. In addition, he was President of the IEEE-Eta Kappa Nu, Epsilon Theta Chapter during 2014-2015. This coming fall, Rafi plans to attend graduate school for electrical engineering at CSULB, after which he aspires to become a successful entrepreneur. Currently, Rafi serves on the IEEE-HKN Board of Governors Public Relations and Communications Committee.

What has it meant to you to be inducted IEEE-HKN?

Being inducted into IEEE-HKN has been a great opportunity for me in terms of recognizing my full potential as a future engineer. Holding various officer positions has greatly benefited my leadership and networking skills. It also helped me earn my first engineering position as a research assistant. And it continues to help me by taking those acquired skills and applying them to whatever responsibilities I have.

Why did you choose to study the engineering field?

I chose to study the field of electrical engineering because I wanted to do something worthwhile and beneficial. I believe engineers develop skills that serve and improve any field they choose to work in. They see the big picture and are problem solvers; they try to treat a non-linear environment as linearly as possible in order to achieve viable results. And, it is within that framework that they come up with creative ideas.

What do you love about engineering?

I love the challenges presented and the determination needed to conquer them. Also, to be able to see the beauty in technology advancements is a gift not to be taken for granted. To take a drawing on paper and transform it into a physical mechanism is rewarding in itself. Electrical engineering lets me take an *intangible idea rooted in theory and develop it into a tangible, realized object.*

Rafi Abdulla Koutoby

What is your dream job?

My dream job would be one in which I can interact with people and help change things for the better by providing renewable energy options, while also allowing me to broaden my horizons. By starting my own business, I hope to end up in a position that lets me oversee the various processes and projects that go into offering people these services.

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

First and foremost, I admire my father. He has been the inspiration I have looked up to since I can remember. His wisdom and dedication to what he holds dear to him have been pillars in my upbringing. I also admire my mother for being my main emotional anchor. Her patience and support have helped to shape who I am today.

What is the next BIG advance in engineering?

In my opinion, in the next ten years, engineering is heading towards alternative energy and energy efficiency. Due to the extended Federal Tax Credit, for the past few years, solar photovoltaics have been the hot topic in renewable energy. In the years to come, solar power will be forced to compete with other types of renewable energy such as hydroelectric, geothermal, wind, and biomass. And the problem of how to use energy most efficiently and responsibly is not only a national concern, but one which a great many nations face at different levels.

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

The most important lesson I've learned is that one can only learn so much in the classroom. It is up to the students to take initiative and become more knowledgeable in an ever-changing and ever-evolving world -- whether it is by keeping up with the latest scientific and technological journals, or by working in the field and learning new things. While doing that extra work may be challenging, it is quite rewarding in many ways, such as being able to put it on a resume, and being a well-rounded person in various fields. Learning is a never-ending process; networking is equally important. In a time when finding a good job is increasingly difficult, knowing the right people can give one a huge advantage.

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

I would advise incoming students to "find someone who can help guide you in your path to becoming a successful engineer. There are teachers who are willing to help you once they see that you are motivated. Finding an internship to obtain hands-on experience is just as important, as that can reinforce your theoretical knowledge into practical experience. Or, it might even inspire you to pursue a different course of specialization you didn't consider before. And, stay well-rounded. As I mentioned, our surroundings are subject to the laws of adapting and changing, so to stay current with a variety of topics gives you more knowledge, and thus more power to be effective in the world."

CALIFORNIA STATE UNIVERSITY LONG BEACH

A Year in the Life of Delta Omega

The 2015-2016 academic year proved to be a tremendous success for the Delta Omega Chapter at the University of Hawaii at Manoa. Through a wide range of community service projects and outreach activities, members were able to build a strong and solid foundation for their IEEE-HKN chapter.

Community service has always been one of Delta Omega's top priorities (last year saw an average of 60+ hours per student member!), and this year was no different. As part of an ongoing tradition, the new student pledges spent their Halloween trick-or-treating to collect donations for UNICEF, a leading humanitarian agency that works globally for the rights of every child. There was quite a variety of creative costumes, including a banana, monkey, shark…and even an avocado! Together, the pledges were able to raise $200 for those in need – just in time for the holiday season.

Chapter members also participated in their annual outreach event, the Junior Engineering Expo, hosted by the College of Engineering. Middle school students from across the state visited the University to learn about science and engineering through interactive games and activities. This year, IEEE-HKN hosted a booth featuring Brushbots. Attendees were provided with Brushbot kits which contained a miniature brush, rubber bands, googly eyes, and batteries. Using these kits, they were able to build their very own Brushbots while also learning about important concepts like friction and electrical currents. Student members assisted and supervised the event, which concluded with a friendly racing competition.

The Delta Omega Chapter continued its efforts this year to improve academic success among students, dedicating over 350 hours to tutoring! The free sessions were held on weekdays in the University's electrical engineering computer lab. Pledges were available to assist their peers in introductory EE courses such as Circuit Analysis, C Programming, and Digital Design. Not only did the students benefit by receiving extra help outside the classroom; the tutors who offered their assistance were also able to develop a stronger sense of EE fundamentals while simultaneously enhancing their leadership and interpersonal communication skills.

In honor of Founder's Day, on October 25, 2015, a celebratory picnic was held at the Manoa Valley District Park. Both current and former Chapter members were invited to attend the special event. The picnic kicked off with a fun icebreaker activity, followed by a potluck lunch that included chili, salad, pie, cake, and more! After lunch, the students played a game of dodge ball and zombie tag, which gave them a chance to socialize while engaging in friendly competition.

Delta Omega has won the Outstanding Chapter Award 17 times, and three of its student members have received the prestigious Outstanding Student Award: Aaron T. Ohta (2003); Blaine Murakami (2005); and Larry Martin (2012). Next year, the Chapter hopes to continue its tradition of excellence through even more activities and projects. In providing networking opportunities for students, as well as outreach events for community members, Delta Omega is proud of its record of service and of the difference all of us make in our communities as chapters of IEEE-HKN.

Professional Inductions

June 2016

Congratulations to our eight Professional Members that were inducted into the Eta Chapter of the IEEE-HKN Board of Governors on 18 June, during the Educational Activities Board Meeting. Candidates for Professional Membership are recommended by an HKN member, based on their contributions and meritorious work in IEEE's fields of interest. Candidates are approved by the IEEE-HKN Board of Governors. Congratulations to: Maja Bystrom (R1), Lorena Garcia (R9), José M. F. Moura (R2), Wanda Reder (R4), Sohaib Qamer Sheikh (R8), Costas M. Stasopoulos (R8), Ravi M.Todi (R6), Jason (Jianchu) Yao (R3).

From left to right: IEEE-HKN President, S. K. Ramesh; Nancy Ostin, Director, IEEE-HKN; Maja Bystrom; Ravi M.Todi; Sohaib Qamer Sheikh; Wanda Reder; Lorena Garcia; José M. F. Moura; Costas M. Stasopoulos; Jianchu (Jason) YAO; and Timothy Kurzweg, IEEE-HKN President-Elect.

Theodore W. Hissey, Jr.

Epsilon Chapter, Penn State University

HKN Alum Celebrates 90th Birthday

At the June IEEE Board Meeting, we celebrated the 90th birthday of Theodore Hissey. 2016 IEEE-HKN President S.K. Ramesh and President-Elect Tim Kurzewg were there to celebrate with him. Ted fondly recalled his induction into the Eta Kappa Nu Epsilon Chapter at Penn State University in 1948.

"TED" Hissey has been a long-time technical and administrative worker for the IEEE, the IEEE Power IEEE Power and Energy Society (PES), and IEEE's corporate administration. He is an engineer, technical manager, and an internationally recognized lecturer and consultant in the field of Electric Power Network Automation and Electric Power Sector Re-structuring. He worked for Leeds and Northrup Company for 43 years in a variety of application, engineering, and management positions.

Ted was elected to serve as Executive Director of IEEE by the IEEE Board of Directors from 1994-1996. He was elected Director Emeritus in 1997, and continues to serve on the IEEE Board of Directors.

His continuing passion and mission is mentoring, promoting, and training young professionals throughout the world in the skills they require throughout their personal and professional lives.

Ted was presented with a cake for his 90th birthday at the IEEE Board Meetings in New Brunswick, NJ in June.

Use Your Required IRA Distribution to Benefit IEEE-Eta Kappa Nu!

by: Stan Retif

As strange as it may seem, there is good news out of Washington, DC. For IEEE members aged 70½ or older, it is now possible to make tax-favored charitable gifts from traditional and Roth IRA accounts.

This past December, in a rare act of bipartisanship, Congress took action that makes permanent this special treatment for gifts completed in 2015 and beyond. A total of up to $100,000 per year may now be transferred directly from traditional or Roth IRAs to one or more qualified charities, such as **Eta Kappa Nu** (IEEE-HKN) via the IEEE Foundation -- **free of federal income tax**. Such generosity **counts toward your required IRA minimum withdrawal** for the year in which the gift was made.

IEEE-HKN depends upon the generous support of members as it strives to foster the highest standards of **Scholarship, Character, and Attitude**. Among the efforts supported through such generosity is the annual **IEEE-HKN Student Leadership Conference**, designed to prepare students for life after school. This three-day event provides IEEE-HKN students with opportunities to enhance their skills and increase their awareness of technology and industry advancements and career development. Perhaps the most important component is the opportunity to network with fellow IEEE-HKN students, faculty advisors, and industry experts.

As always, it is recommended that you seek the counsel of your own tax or financial advisor. They can provide input about the advantage of directly transferring gifts from your retirement plan to the IEEE Foundation. Your accountant and/or advisor may also help you determine the optimum amount to give from retirement plan accounts under federal and state tax laws.

Please note, it is important not to withdraw funds prior to a gift, but have the gift amount distributed directly from an IRA to your designated qualified charity. For those with check writing privileges on their accounts, this may be the easiest way to make gifts directly from an IRA.

To help us track your generosity, please inform us of your intent to make a gift benefitting IEEE-HKN to the IEEE Foundation from your IRA. For more information about supporting the IEEE-HKN with a planned gift, email Stan Retif, or phone him at +1-732-562-2632.

Thank you for your involvement in IEEE-HKN!

IEEE-HKN AWARDS UPDATE

Three individuals have been selected this year to be recognized for their achievements. These nominations by the IEEE-HKN Awards Committee were approved by the IEEE-HKN Board of Governors and the IEEE Educational Activities Board. The awards will be presented during the 19 November 2016 IEEE EAB Awards Ceremony in New Brunswick, NJ, USA. Their accomplishments will be featured in the February 2017 issue of THE BRIDGE.

2016 IEEE-HKN C. Holmes MacDonald Outstanding Teaching Award:

Dr. Ronald Joe Stanley

Gamma Theta Chapter
Missouri S&T

"by virtue of his contributions to engineering education and his dedication to pre-college outreach"

2016 IEEE-HKN Outstanding Young Professional Award:

Dr. Salvatore Campione

"for his contributions to the electromagnetic modeling of complex systems and structures from microwave to optical frequencies"

EEE-Eta Kappa Nu 2016 Distinguished Service Award:

Dr. David L. Soldan

Beta Kappa Chapter
Kansas State University

"for exceptional leadership and life-long support and service to Eta Kappa Nu and IEEE-Eta Kappa Nu members, chapters, and volunteers"

"Cute and Smart"

Pictured is Natalie, daughter of Amy Recine, former IEEE-HKN Activities Program Manager, and current Product Manager, Continuing and Professional Education for IEEE Educational Activities.

Natalie shows us she is both "cute and smart" and "born to be Eta-Kappa-Nu!"

Know a child destined for IEEE-HKN?

Share your IEEE-HKN pride…email info@hkn.org to get a free baby bib for your child. Send us a photo of your child wearing the bib, and he or she may be included in a future issue of THE BRIDGE, or included in IEEE-HKN social media content.

IEEE-HKN -- Raising the next generation of engineers!

◀ Pictured is Natalie Recine, daughter of John and Amy Recine.

List of Candidates for the 2017 IEEE-HKN Board of Governors Elections:

Election Information:

- Each IEEE-HKN active chapter receives one vote in the election. To achieve "active" status, a chapter must have submitted inductee documentation and payment, or an annual report, to IEEE-HKN Headquarters at least once since 1 January 2014.
- The election will run during the period 1 October through 1 November. Each active chapter will receive an email link to the ballot. Each active chapter is asked to hold an IEEE-HKN meeting during this timeframe to explain the ballot and election process, distribute/review information on the candidates, and take a vote on each item as indicated on the ballot. If no regular meetings of the chapter are scheduled during this timeframe, a special meeting should be called.
- Each chapter will have one vote for each position, dependent on their region.
- It is critical that all active chapters participate in the election process. Every active chapter should make every effort to participate in this activity.
- If more than one ballot is sent from a chapter, the first one received will be the ballot that is counted and considered valid.

Election information and candidate bios can be found on our website. If you have any questions about this process, please contact info@hkn.org.

2017 President-Elect:

- **Thomas M. Talavage**: IEEE Region 4, Central Indiana Section - Professor at Purdue University (Beta Chapter)
- **Steve E. Watkins**: IEEE Region 5, Saint Louis Section, Professor at Missouri University of Science and Technology (Gamma Theta Chapter)

2017-2019 Region 1-2:

- **Karen Panetta**, IEEE Region 1, Boston Section - Associate Dean for Graduate Education and Professor at Tufts University (Epsilon Delta Chapter)
- **Marc Apter**, IEEE Region 2, Northern Virginia Section (Eta Chapter)

2017-2019 Region 7-10 Governor:

- **Tariq S. Durrani**, IEEE Region 8, United Kingdom and Ireland Section - Professor at University of Strathclyde in Glasgow (Eta Chapter)
- **Enrique M Tejera**, IEEE Region 9, Panama Section - Manager of the High Voltage Section with the Panama Canal (Eta Chapter)

2017-2019 Member:

- **Tom Habetle**r, IEEE Region 3, Atlanta Section - Professor at Georgia Institute of Technology (Beta Mu Chapter)
- **Kyle Lady**, IEEE Region 4, Southeastern Michigan Section - Senior R&D Engineer at Duo Security (Beta Epsilon Chapter)

2017 Student Representative:

- **Michael Benson**, IEEE Region 4, Southeastern Michigan Section - Full-time PhD student at University of Michigan - Ann Arbor (Beta Epsilon Chapter)
- **Garrett Hall**, IEEE Region 5, Central Texas Section - Full-time undergraduate student and considered a full-time Senior at University of Texas at San Antonio (Kappa Upsilon Chapter)
- **Rafi Koutoby,** IEEE Region 6, Coastal Los Angeles Section - California State University, Long Beach (Epsilon Theta Chapter)

CHAPTER DIRECTORY

Air Force Institute of Technology: Delta Xi Chapter
Arizona State University: Epsilon Beta Chapter
Auburn University: Xi Chapter
Baylor University: Kappa Tau Chapter
Bharati Vidyapeeth College of Engineering: Lambda Eta Chapter
Boise State University: Kappa Pi Chapter
Boston University: Kappa Sigma Chapter
Bradley University: Delta Upsilon Chapter*
Bringham Young University: Zeta Eta Chapter
California State University-Northridge: Lambda Beta Chapter
California Polytechnic State University: Epsilon Phi Chapter
California State Polytechnic University: Zeta Theta Chapter
California State University-Chico: Iota Zeta Chapter*
California State University-Fullerton: Iota Omega Chapter
California State University-LA: Epsilon Nu Chapter
California State University-Long Beach: Epsilon Theta Chapter
California State University-Fresno: Theta Kappa Chapter
Capitol College: Kappa Mu Chapter*
Carnegie-Mellon University: Sigma Chapter
Case Western Reserve University: Zeta Chapter
Chulalongkorn University: Mu Theta Chapter
City College of New York: Beta Pi Chapter
Clarkson College: Gamma Gamma Chapter
Clemson University: Zeta Iota Chapter
Cleveland State University: Epsilon Alpha Chapter
Colorado State University: Delta Pi Chapter
Columbia University: Gamma Lambda Chapter*
Cooper Union: Delta Chi Chapter
Cornell University: Kappa Chapter
Dalhouse University: Lambda Theta Chapter
Drexel University: Beta Alpha Chapter
Duke University: Delta Lambda Chapter
Eastern Washington University: Mu Delta Chapter
Embry-Riddle Aeronautical University-Daytona Beach: Lambda Upsilon Chapter
Embry-Riddle Aeronautical University-Prescott: Kappa Iota Chapter
Fairleigh Dickinson University: Theta Gamma Chapter*
Florida A&M University-Florida State University College of Engineering: Lambda Delta Chapter
Florida Institute of Technology: Zeta Epsilon Chapter
Florida International University: Kappa Delta Chapter
Gannon University: Iota Nu Chapter
George Mason University: Iota Mu Chapter*
George Washington University: Theta Iota Chapter
Georgia Institute of Technology: Beta Mu Chapter
Hofstra University: Lambda Xi Chapter
Howard University: Lambda Gamma Chapter
Illinois Institute of Technology: Delta Chapter
Iowa State University: Nu Chapter
Johns Hopkins University: Gamma Upsilon Chapter
Kansas State University: Beta Kappa Chapter
Kettering University: Theta Epsilon Chapter
Khalifa University: Lambda Phi Chapter
Lafayette College: Gamma Psi Chapter
Lamar University-Beaumont: Delta Beta Chapter
Lawrence Institute of Technology: Theta Upsilon Chapter
Lehigh University: Chi Chapter
Louisiana State University: Delta Iota Chapter
Louisiana Technological University: Delta Gamma Chapter
Manhattan College: Gamma Alpha Chapter
Marquette University: Beta Omicron Chapter
Massachusetts Institute of Technology: Beta Theta Chapter
Miami University: Lambda Omicron Chapter
Michigan State University: Gamma Zeta Chapter
Michigan Technological University: Beta Gamma Chapter
Milwaukee School of Engineering: Iota Beta Chapter
Mississippi State University: Gamma Omega Chapter
Missouri University of Science and Technology: Gamma Theta Chapter
Monmouth University: Zeta Alpha Chapter*
Montana State University: Iota Kappa Chapter
National University of Singapore: Lambda Omega Chapter
Naval Postgraduate School: Theta Delta Chapter
New Jersey Institute of Technology: Gamma Kappa Chapter
New Mexico State University: Gamma Chi Chapter
New York Institute of Technology-Old Westbury: Iota Psi Chapter*
New York Institute of Technology: Kappa Zeta Chapter*
New York Polytechnic School of Engineering: Theta Theta Chapter*
New York Polytechnic: Beta Beta Chapter**
New York University: Beta Zeta Chapter**
North Carolina A&T State University: Theta Nu Chapter*

North Carolina State University: Beta Eta Chapter
North Dakota State University: Gamma Tau Chapter
Northeastern University: Gamma Beta Chapter
Northern Illinois University: Kappa Alpha Chapter*
Northrop University: Zeta Mu Chapter**
Northwestern University: Beta Tau Chapter
Norwich University: Theta Xi Chapter
Oakland University: Iota Chi Chapter*
Ohio State University: Gamma Chapter
Ohio University: Delta Epsilon Chapter
Oklahoma State University: Omega Chapter
Old Dominion University: Zeta Upsilon Chapter*
Oregon State University: Pi Chapter
Pennsylvania State University: Epsilon Chapter
Polytechnic University of New York: Zeta Sigma Chapter
Portland State University: Iota Theta Chapter
Prairie View A&M University: Zeta Lambda Chapter
Pratt Institute: Delta Theta Chapter**
Princeton University: Epsilon Pi Chapter*
Purdue University-Indianapolis: Kappa Rho Chapter*
Purdue University: Beta Chapter
Rensselaer Polytechnic Institute: Beta Nu Chapter
Rochester Institute of Technology: Iota Iota Chapter*
Rose-Hulman Institute of Technology: Epsilon Eta Chapter
Rutgers University: Gamma Epsilon Chapter
San Diego State University: Zeta Tau Chapter
San Jose State University: Epsilon Iota Chapter
Santa Clara University: Epsilon Psi Chapter*
Singapore University of Technology and Design: Mu Epsilon Chapter
South Dakota School of Mines & Technology: Beta Chi Chapter
South Dakota State University: Gamma Rho Chapter
Southern California Institute of Technology: Iota Pi Chapter*
Southern Illinois University-Carbondale: Lambda Epsilon Chapter
Southern Illinois University-Edwardsville: Theta Omicron Chapter*
Southern Methodist University: Gamma Omicron Chapter
Southern University A&M: Zeta Psi Chapter
St. Cloud State University: Iota Omicron Chapter*
St. Louis University: Delta Psi Chapter*
State University of New York at Buffalo: Zeta Pi Chapter
State University of New York at Stony Brook: Theta Mu Chapter
State University of New York-Binghamton: Kappa Epsilon Chapter
State University of New York-New Paltz: Kappa Omicron Chapter
Stevens Institute of Technology: Iota Delta Chapter
Syracuse University: Gamma Eta Chapter*
Tecnológico de Monterrey: Lambda Rho Chapter
Temple University: Iota Sigma Chapter
Tennessee State University: Zeta Kappa Chapter
Tennessee Technological University: Epsilon Rho Chapter
Texas A&M Qatar: Lambda Mu Chapter
Texas A&M University-Kingsville: Zeta Beta Chapter
Texas A&M University: Gamma Mu Chapter
Texas Tech University: Gamma Nu Chapter
Trine University: Zeta Phi Chapter
Tufts University: Epsilon Delta Chapter
Tulane University: Theta Alpha Chapter*
Tuskegee University: Epsilon Upsilon Chapter
UCSI University-Kuala Lumpur: Mu Alpha Chapter
Union College: Phi Chapter
Union University: Lambda Pi Chapter
United States Military Academy: Iota Phi Chapter
University of Akron: Zeta Zeta Chapter*
University of Alabama-Birmingham: Iota Alpha Chapter*
University of Alabama: Delta Nu Chapter
University of Alabama-Huntsville: Theta Eta Chapter
University of Alaska-Anchorage, Fairbanks: Kappa Gamma Chapter*
University of Arizona: Iota Xi Chapter
University of Arkansas: Gamma Phi Chapter
University of Bridgeport: Theta Sigma Chapter
University of California-LA: Iota Gamma Chapter
University of California-San Diego: Kappa Psi Chapter
University of California-Santa Barbara: Epsilon Tau Chapter*
University of California-Riverside: Lambda Sigma Chapter
University of California-Berkeley: Mu Chapter
University of California-Irvine: Zeta Omega Chapter
University of Central Florida: Zeta Chi Chapter
University of Cincinnati: Tau Chapter
University of Colorado-Colorado Springs: Theta Chi Chapter*
University of Colorado-Denver: Theta Zeta Chapter*
University of Colorado-Boulder: Rho Chapter
University of Connecticut: Beta Omega Chapter
University of Dayton: Iota Eta Chapter

University of Delaware: Epsilon Omicron Chapter
University of Denver: Delta Delta Chapter*
University of Detroit Mercy: Beta Sigma Chapter
University of District of Columbia: Iota Tau Chapter*
University of Florida: Epsilon Sigma Chapter
University of Hartford: Iota Epsilon Chapter
University of Hawaii at Manoa: Delta Omega Chapter
University of Hong Kong: Lambda Iota Chapter
University of Houston: Epsilon Epsilon Chapter*
University of Illinois at Urbana-Champaign: Alpha Chapter
University of Illinois-Chicago: Iota Lambda Chapter
University of Iowa: Beta Iota Chapter*
University of Johannesburg: Lambda Psi Chapter
University of Kansas: Gamma Iota Chapter
University of Kentucky: Beta Upsilon Chapter
University of KwaZulu-Natal : Mu Eta Chapter
University of Louisville: Epsilon Chi Chapter*
University of Maine: Delta Kappa Chapter
University of Maryland-College Park: Gamma Xi Chapter
University of Massachusetts-Amherst: Delta Eta Chapter
University of Massachusetts Dartmouth: Zeta Xi Chapter
University of Massachusetts-Lowell: Epsilon Zeta Chapter
University of Memphis: Kappa Lambda Chapter
University of Miami: Epsilon Kappa Chapter
University of Michigan: Beta Epsilon Chapter
University of Michigan-Dearborn: Theta Tau Chapter
University of Minnesota: Omicron Chapter
University of Mississippi: Epsilon Omega Chapter
University of Missouri-Columbia: Iota Chapter
University of Missouri-Kansas City: Theta Pi Chapter
University of Nebraska: Beta Psi Chapter
University of Nevada-Reno: Theta Psi Chapter*
University of New Haven: Zeta Rho Chapter
University of New Mexico: Delta Omicron Chapter
University of New Orleans: Iota Rho Chapter*
University of North Carolina at Charlotte: Kappa Phi Chapter
University of North Dakota: Delta Rho Chapter
University of North Florida: Kappa Nu Chapter
University of North Texas: Lambda Zeta Chapter
University of Notre Dame: Delta Sigma Chapter
University of Oklahoma: Beta Xi Chapter
University of Pennsylvania: Lambda Chapter
University of Pittsburgh: Beta Delta Chapter
University of Portland: Theta Beta Chapter*
University of Puerto Rico at Mayaguez: Lambda Tau Chapter
University of Rhode Island: Zeta Gamma Chapter
University of San Diego: Kappa Eta Chapter
University of Scranton: Lambda Nu Chapter
University of South Alabama: Theta Lambda Chapter
University of South Carolina: Delta Phi Chapter
University of South Florida: Kappa Xi Chapter
University of Southern California: Upsilon Chapter
University of Southwestern Louisiana: Delta Tau Chapter
University of Tennessee: Beta Phi Chapter
University of Texas at Arlington: Epsilon Mu Chapter
University of Texas at El Paso: Zeta Delta Chapter
University of Texas-Austin: Psi Chapter
University of Texas-Dallas: Kappa Kappa Chapter
University of Texas at San Antonio: Kappa Upsilon Chapter
University of the Pacific: Theta Omega Chapter
University of Toledo: Epsilon Gamma Chapter*
University of Tulsa: Zeta Nu Chapter
University of Utah: Gamma Sigma Chapter
University of Virginia: Gamma Pi Chapter
University of Washington: Iota Upsilon Chapter
University of West Florida: Lambda Alpha Chapter
University of Wisconsin-Platteville: Kappa Theta Chapter
University of Wisconsin: Theta Chapter
US Naval Academy: Lambda Kappa Chapter
Vanderbilt University: Epsilon Lambda Chapter
Villanova University: Delta Mu Chapter
Virginia Commonwealth University: Kappa Chi Chapter
Virginia Military Institute: Theta Phi Chapter*
Virginia Tech: Beta Lambda Chapter
Washington University-St. Louis: Delta Zeta Chapter
Wayne State University: Delta Alpha Chapter*
West Virginia Institute of Technology: Zeta Omicron Chapter*
West Virginia University: Beta Rho Chapter
Western Michigan University: Kappa Omega Chapter
Western Washington University: Mu Zeta Chapter
Wichita State University: Epsilon Xi Chapter
Wilkes University: Kappa Beta Chapter*
William Marsh Rice University: Theta Rho Chapter
Worcester Polytechnic Institute: Gamma Delta Chapter

***= Inactive Chapter **= Closed Chapter**