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Illuminating Sound: Imaging Tissue Optical Properties with Ultrasound

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In recent years, the diagnostic imaging community has shown considerable interest in developing techniques for measuring the optical properties of tissue with high spatial resolution[1]. The optical properties governing light propagation through tissue include absorption and scattering. Absorption in the visible and near-infrared wavelength range is related to tissue molecular structure; its measurement allows one to determine functional information, such as oxygen saturation in blood, and can potentially allow one to distinguish between tissue constituents based on absorption spectra. Optical scattering, on the other hand, depends on the cellular architecture of tissue. It is the strong optical scattering exhibited by biological tissue that makes deep-tissue imaging challenging, particularly when good spatial resolution is desired.

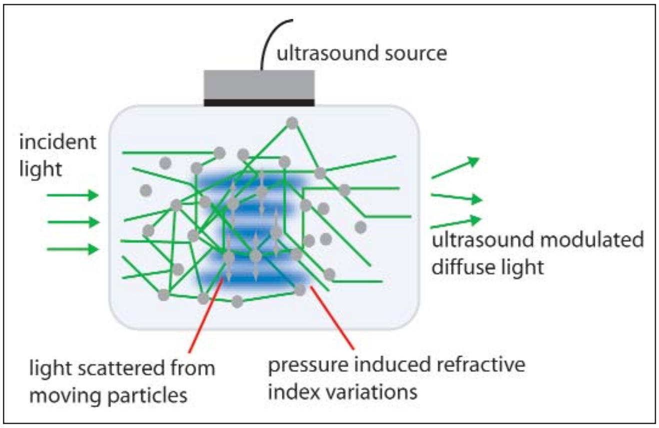

Figure 1. The primary mechanisms for the ultrasound modulation of light in scattering media.

Light propagation through tissue is inherently diffusive; photons follow a random walk in a manner analogous to heat flow. Techniques such as confocal optical microscopy and optical coherence tomography achieve excellent resolution, but the image is formed using ballistic or quasi-ballistic light and thus is limited to depths of 1-2mm[2]. With diffuse optical tomography (DOT), modulated laser light illuminates the medium, an array of optical detectors measures the magnitude and phase of the diffuse optical field emitted by the sample, and a tomographic reconstruction yields an image[3]. While DOT is undoubtedly a powerful imaging modality suitable for deep-tissue imaging, resolution is limited (to approximately 1 cm) owing to the diffuse nature of light.

Acousto-optic (AO) sensing is a new hybrid technique that combines ultrasound with diffuse light to achieve deep-tissue imaging of optical properties with the spatial resolution of ultrasound. In this technique, the sample is simultaneously insonofied by an ultrasound beam and illuminated with a laser source, producing a diffuse optical field within the sample volume. The ultrasound modulates the optical field in the AO sensing volume, defined as the region where the light and sound overlap. In essence, the ultrasound "tags" the light traversing the sensing volume and detection of this tagged light gives an indication of the strength of the AO interaction. The AO signal scales with the optical flux through the sensing volume and is thus indicative of the local optical properties of the tissue–in particular the local absorption coefficient. By pulsing the ultrasound and scanning the beam across a plane in a manner similar to conventional B-mode ultrasound imaging, a 2-D acousto-optic image can be constructed. The net result is a subsurface image of the acousto-optic interaction strength *at depth and with a spatial resolution dictated by the ultrasound field*.

While the mechanism for the interaction of ultrasound with ballistic light has been well understood for quite some time, the physics of diffuse light interaction with ultrasound has received only limited attention[4]. There are two primary mechanisms through which ultrasound modulates the optical field (see Fig. 1). First, as light travels the tortuous path through the ultrasonic field it accumulates a phase shift due to multiple reflections from moving particles. Secondly, the index of refraction of the media is altered by the pressure field via the piezo-optic effect, leading to an additional phase change. Both of these effects are modulated at the ultrasound frequency, and their relative contributions depend on the ratio between the mean optical path length between scattering events and the acoustic wavelength. If the path length is large compared to the wavelength then variations in the index of refraction tend to dominate the response.

The use of ultrasound to modulate a diffuse optical field was first reported in the early 1990's[5], and the potential of this technique for optical imaging was outlined soon thereafter [6,7]. One of the key limitations in AO imaging has been in understanding how to detect the phase shift imparted on the modulated light given that the light levels, after passing through an optically diffuse media, are extremely low and come with a strong background of unmodulated light. This is further complicated by the fact that the modulated light emanating from a highly diffuse media has a *spatially random* phase shift. Interference between modulated and un-modulated light leads to the formation of a time-varying speckle pattern incident on the aperture of the optical detector. Each individual speckle is modulated at the ultrasound frequency, but the phase of this time- varying signal is random from speckle to speckle. Early AO systems relied on detecting the modulation of a single optical speckle, resulting in extremely low light levels. In order to improve the signal to noise ratio, these systems used continuous (CW) ultrasound, allowing for narrow bandwidth detection at the expense of spatial resolution along the ultrasound axis.

Two techniques have emerged for the high sensitivity detection of tagged photons in biological media. The first is a parallel lock-in detector that allows for the simultaneous detection of a large number of speckles using a CCD camera[8]. This approach boosts signal-to-noise ratio over single speckle detection and is suitable for measuring acousto-optic signals using pulsed ultrasound[9]. More recently, a photorefractive crystal (PRC) based interferometry technique has emerged that has sufficient sensitivity to detect acousto-optic signals generated by a pulsed ultrasonic source at clinically relevant pressure levels[10]. Figure 2 illustrates the basic experimental setup used in the PRC approach. A laser source is divided into a signal beam that illuminates the sample, and a reference beam that is sent directly to the PRC. Scattered light from the sample is collected and mixed with the reference beam in the PRC. The local index of refraction in the PRC changes in response to the complex optical interference pattern set up in the crystal, and the reference beam diffracts off of this grating in a process called two-wave mixing. The crystal thus acts as a real time hologram, and the diffracted reference beam is an exact replica of the signal beam, less any high frequency (i.e. ultrasonic) modulation that exceeds the crystal response time. This diffracted reference beam is *in-phase* with the transmitted signal beam, and the two beams interfere constructively at the detector. In the presence of ultrasound, the phase of the signal beam is shifted with respect to the reference, leading to a *decrease* in the intensity at the detector. This AO signal sums coherently over space, regardless of the fact that the phase shift imparted on the diffuse optical field by the ultrasound is spatially random.

Figure 3 shows AO signals observed in a highly scattering tissue phantom using a 3-cycle ultrasound pulse at a frequency of 5 MHz. As the ultrasound propagates through the phantom, the magnitude of the acousto-optic signal (with respect to the steady-state background) gives a measure of the strength of the acousto-optic interaction and is affected by, among other things, the amount of light in the interaction region, the ultrasound pressure, and the sensing volume. In the case when the ultrasound passes through a homogeneous region of tissue phantom (Traces A and C), the signal tracks the envelope of the background light distribution, with the spatial resolution controlled by the beam width and the ultrasound pulse length. If there is an optical absorber embedded in the phantom, the magnitude of the AO signal decreases when the ultrasound pulse passes the absorber (Trace B). In a sense, the AO interaction region acts like a virtual light source that one uses to probe the local optical properties of the medium.

Using pulsed ultrasound to pump the AO response offers

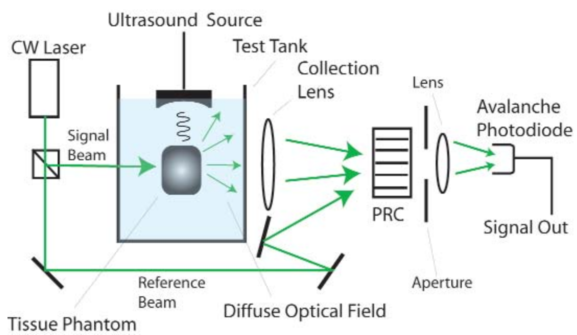

Figure 2. A basic experimental set-up for acousto-optic imaging using a PRC interferometry system.

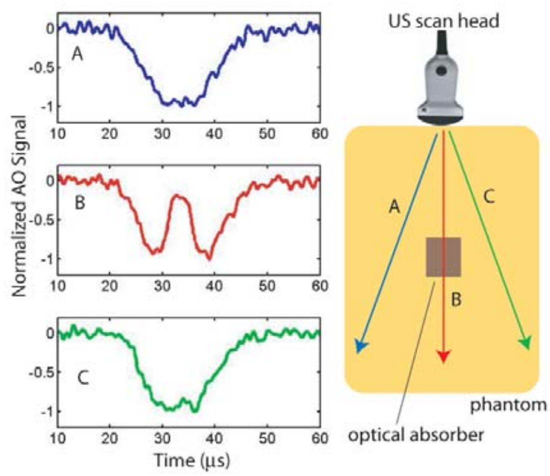

Figure 3. Acousto-optic signals measured along several scan lines in a tissue phantom with an embedded optical absorber.

Illuminating Sound

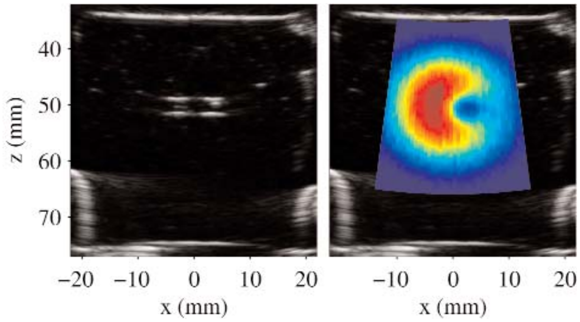

Figure 4. B-mode ultrasound (left) and AO images of a tissue phantom with two embedded inclusions. The inclusion on the right has been infused with an optically absorbing dye.

key advantages over narrowband, CW systems: it minimizes deleterious bioeffects due to tissue heating, it offers good spatial resolution along the ultrasound axis, and it allows for the use of a conventional ultrasound imaging system to simultaneously generate acousto-optic and B-mode ultrasound images[11]. Such images are intrinsically co-registered and yield complementary mechanical and optical contrast information. Figure 4 (left) shows a B-mode ultrasound image of a gel-based tissue phantom with optical and acoustic properties similar to breast tissue. Two targets are placed in the phantom with acoustic properties matching that of the surrounding media, and one of the targets was infused with an optically absorbing dye. The target boundaries are seen on the ultrasound image due to a slight impedance mismatch introduced by the fabrication process. The AO image of the same phantom is given in Fig. 4 (right). In the absence of an absorbing target, this image would be a uniformly illuminated red circle indicative of the background light distribution. The addition of an optically absorbing target (on the right) results in a blue spot that is clearly resolved in the AO image.

Acousto-optic imaging is a promising new modality, which could fuel improvements in the detection and characterization of any tissue abnormalities that exhibit concomitant changes in optical properties. One target application is in the diagnosis of breast cancer, where a dual mode ultrasound/AO system may provide improvements in the ability to differentiate benign from malignant lesions. Technical challenges in the transition from a laboratory to a clinical setting are primarily associated with the sensitivity limitations imposed by the low photon flux and overcoming the effects of physiological motion on the diffuse optical field. Recent advances in the detection of AO signals, however, offer hope that dual-mode ultrasound/AO imaging *in vivo* may be just over the horizon.

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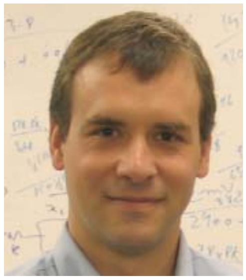

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ECHOES

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The Acoustical Society of America was organized in 1929 to increase and diffuse the knowledge of acoustics and to promote its practical applications.

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ASA and ASJ return to Honolulu

ASA and ASJ plan 4th joint meeting in Honolulu

Continuing a tradition that began in 1978, the Acoustical Society of Japan will join the Acoustical Society of America in the fourth joint meeting in Honolulu, Hawaii, November 28 to December 2. This meeting promises to be the largest joint meeting yet!

The technical program includes 1626 papers organized into 125 sessions covering all aspects of acoustics, jointly organized and jointly chaired by ASA and ASJ members. The opening plenary session on Tuesday, November 28, will include plenary talks by Lawrence Crum (University of Washington) and Masayuki Morimoto (Kobe University).

Special sessions honor Arthur Myrberg, Manfred Schroeder, Floyd Dunn, Frederick Fisher, and Leonid Brekhovskikh.

Inter-Noise 2006 will follow the joint meeting on December 3-6 at the Sheraton Waikiki. Details on this meeting can be found at www.internoise2006.org.

Honolulu and Hawaii offer many attractions for meeting attendees, including spectacular scenery and beautiful weather. In downtown Honolulu are the Iolani Palace, the Bishop Museum, the State Capitol, and Chinatown. At the north end of Oahu, about an hour's drive from Honolulu, is the Polynesian Cultural Center with displays of art and culture from many Pacific islands and a concert of music and dance each evening.

Social events include a buffet social on the lawn of the Royal Hawaiian Hotel on Wednesday and a banquet at the Sheraton Waikiki Hotel on Friday featuring a seven-course Chinese dinner and special Hawaiian music. The awards ceremony will be held at the banquet. A hospitality room for accompanying persons, open 8:00 am to 5:00 pm Tuesday through Friday, will include lei making and a hula demonstration.

The first joint ASA/ASJ meeting was the work of many people. John Burgess, the Chair of that meeting, credits Edgar Shaw, then president of ASA, with the idea, but the hard work of John Burgess and Hiroya Fujisaki made that meeting a reality. Tony Embleton chaired the Technical Program Committee, The rest, as the say, is history. John will share with us several historical anecdotes about the creation and organization of the first joint meeting in the Program of the 4th joint meeting.

Members of the Technical Program Organizing Committee.

A Second Pair of Ears

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"Hey, four eyes!" I remember that expression from my elementary school days. Of course, I didn't actually have four eyes. Our ears are another story. Superficially there are two but each houses two organs, one exclusively auditory and another generally vestibular, that is, maintaining our balance, but secondarily can be stimulated with sound under the proper conditions. One of the vestibular organs, the saccule, serves as an auditory receptor in fish, amphibians and reptiles. The feature that makes otolith organs distinct is that most of its hair cells are embedded in a layer of gel on which lie little "rocks" of calcium carbonate. Otolith organs act as tiny mass/spring acceleration sensors, detecting motion or vibration. In the course of evolution, transitioning from living in a watery medium to a terrestrial one, could mammals have retained this primitive hearing ability in their saccules? There have been reports that the saccule does indeed serve some auditory function, but our awareness of it is masked by the dominant role of the much more sensitive cochlea in human auditory perception.

The saccule is situated very close to the stapes, the final middle ear bone which links the sound-pressure-induced vibration of the eardrum with the displacement of fluid in the inner ear. Since fluid is incompressible, the inner ear has two membranes or windows that stretch to allow fluid movement. The footplate is inserted in one, the oval window and the second, the round window, moves out of phase as a pressure-release mechanism. With moderate sound pressures at the eardrum, the saccule is not affected; however at high sound pressures the saccule is stimulated which can account for complaints of disorientation with high intensity exposure. Sound pressures in excess of 100 dB SPL are required to activate the saccule, leading to the intriguing hypothesis (advanced by Todd *et al.*) that rock music is intense in order to stimulate these old reptilian ears of ours.

In fact the frequency range of human saccular hearing overlaps quite well with that of living turtles, which are often viewed as living forms of primitive reptiles. Turtles hear frequencies below 1000 Hz; typically they are most sensitive in the 200-5000 Hz range, exactly like human saccular hearing. What is more interesting is that all turtles studied (Wever) have a unique connection between their middle ear bone and the saccule. Fibroelastic stapido-saccular strands attach the end of the middle ear bone (columella) to the saccular wall, thus displacement of the eardrum drives both the saccule and the cochlea. Turtles have a dual hearing system; each overlying in frequency range, but probably differing in sensitivity to airborne, waterborne and substrate stimulation.

The hearing capabilities of two marine turtles are presented in Figure 1 (right). The anatomy of the stapedio-saccular strands is presented on the left. The hearing thresholds for the green turtle, *C mydas*, are from Ridgway *et al.*, using cochlear microphonics recorded in response to a vibrator driving the eardrum. The second set of threshold values are derived from a submerged loggerhead, *C. caretta*, using sound induced behavioral (head contraction) responses. Both are referenced to displacement and both are in good agreement given the different species and methodologies. In each instance, the responses are likely the result of both saccular and cochlear activation. The cochlea may be the more sensitive of the two systems, as is the case in humans.

It is unclear if these strands existed in stem reptiles to assist them hear as they slithered close to or on surfaces or if the strands represented a specific adaptation to life in a shell, since vibratory stimulation of the shell activates the ear by bone conduction even when the head is retracted. There may have been an advantage of hearing with two receptors in the inner ear, especially in large animals that lived close to the substrate or were amphibious. Mammals evolved in a different niche; mass gave way to light and fast bodies, thus the coupling of the saccule to the earth was greatly reduced and mechanisms enhancing that coupling became less useful to survival. In humans, the saccule serves primarily a vestibular role, given its high threshold to sound and its physical isolation in terms of distance from the substrate.

In the case of cochlear deafness is vestibular hearing a rehabilitative alternative? When a surgical window is created in the vestibular system, specifically in the wall of one of the three semicircular canals, these organs respond vigorously to vibration. Amazingly, deaf subjects with such surgical windows are able to detect sound delivered as bone conduction vibration to the head at levels approaching the lower limits of normal hearing. Drawbacks include some imbalance but far more importantly there was a complete lack of any speech understanding since the canals are not wired to the auditory parts of the brain. The saccule is different; for it, such auditory brain connections do exist.

An alternative approach to fenestration (creating a new window) is to extend the middle ear system such that the part of

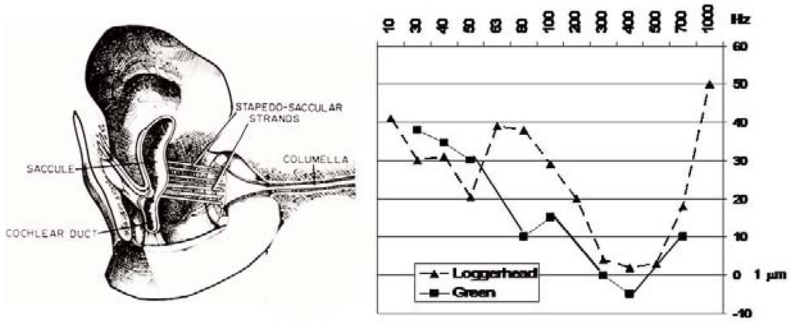

Figure 1. Turtle saccular coupling and audiogram

A Second Pair of Ears

the stapes (a bone in the middle ear) is directly coupled to the wall of the saccule. That approach has already been tested in nature by various species of turtles for well over 200 million years. Silicone struts, modeled to biomechanically mimic turtle strands, were developed. Struts are extruded through holes drilled in the stapes footplate to make contact with the saccular wall a mere 1.5 mm away. This human otosurgery has yet to be performed but success with related saccular surgery is encouraging. The human saccule is thought to respond maximally around 300 Hz with an upper range of about 1000 Hz, a range that overlaps with turtle audiograms. In the case of deafness, speech cues as the fundamental frequency, the first formant and prosodic features can be readily amplified and delivered into the ear canal through the use a stand-alone saccular hearing aid. The prototype saccular hearing aid employs a processing algorithm that filters speech, half-wave rectifier and modulates the result on a tonal or low pass noise carrier. Intelligibility is acceptable with a 250-Hz upper sideband signal given the low frequency spectra. This signal, if delivered to the skin through vibrators, produces a tactile sensation the cues speech is present.

The Saccular hearing aid can be used in conjunction with cochlear implants. Implants do not stimulate the cochlear apex; hence low frequency information is not transmitted into the electric code. It seems reasonable that a combination hearing device would afford more flexibility in remediation of deafness than a single approach.

The stapedial-saccular strut procedure can also serve as a supplement to an audible ultrasonic hearing aid for the deaf. Ultrasound (~20-100 kHz) is audible by fluid or bone conduction, even in some deaf individuals with vestibular function. Brain imaging indicates low frequency ultrasound (20-60 kHz) activates the auditory cortex, likely via both cochlear and saccular stimulation in normal hearing listeners and probably only by the saccular activation in the cases of complete deafness (Lenhardt). Intense ultrasound, modulated by speech, enters the inner ear through the fluid channel of the endolymphatic duct, the cochlear aqueduct or any vascular pathway; but first the signal is demodulated by the nonlinearities in the fluid within the head, i.e., the brain. The resulting inner ear high-frequency displacement is near cochlear base activating first the cochlea or then the saccule if higher stimulus amplitudes are employed. The mechanism of ultrasonic hearing is depicted in Figure 2.

Cochlear deafened listeners fitted with ultrasonic hearing aids, generally experience intelligibility on the order of 50% correct with practice, presumably through saccular mediation. Low frequency speech cues through the saccular hearing aid added to the ultrasonic cues would likely increase functionality; but that's something that needs to be tested and confirmed. The speech signals would be coherent, differing in carrier frequency and some processing; the brain effect of each should be additive, enhancing perception.

The auditory aspect of the human saccule has been elusive, co-existing in the shadow of the much more powerful cochlea, but its hidden role in hearing is slowly but steadily being realized. With this novel bio-inspired engineered technology, that freedom may come a little easier, thanks to turtles.

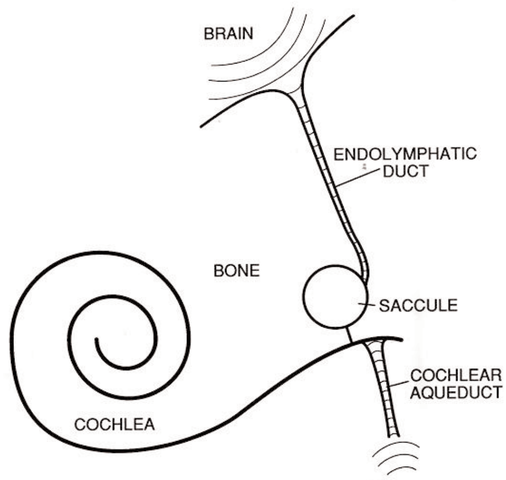

Figure 2. Mechanism of ultrasonic hearing

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This is adapted from paper 5aABa10 presented at the ASA meeting in Providence.

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Good books I have read

Architectural Acoustics
by Marshall Long

(Elsevier Academic Press, ISBN 13: 978-0-12-344441-8)

Thomas D. Rossing

This is a large (844 page) and comprehensive book with a lot of interesting information. Rather than a "good book I have read" I should describe it as a "good book I have scanned and read in part." It covers the field of architectural acoustics more thoroughly than any book I have read, and it is written in a style that makes it interesting to read.

The goal is to "present a technical overview of architectural acoustics at a level suitable for an upper division undergraduate or an introductory graduate course." The author presents algorithms useful for problem solving, but unfortunately includes no problems, which may limit its usefulness as a textbook. Hopefully some teacher will write a set of problems, including computational problems, that will make it more useful for courses at this level.

It begins with a nice historical introduction, which is followed by chapters on acoustics fundamentals and human perception and reaction to sound. The following ten chapters, constituting about half of the book, treat the fundamentals of environmental noise, interaction with solids, sound in enclosed spaces, vibration, noise transmission in floors, mechanical systems and ducts. The remainder of the book treats design of multifamily dwellings, office buildings, rooms for speech, sound systems, rooms for music, studios, and multipurpose rooms. The final chapter is an update on acoustic modeling and auralization.

The book is well illustrated, and the mathematical level is appropriate to its intended audience. I liked the book very much, and I look forward to reading thorough reviews by experts in architectural acoustics who will no doubt identify features and shortcomings that I missed.

WESPAC IX

Thomas D. Rossing

WESPAC IX in Seoul, Korea, June 26-28, with more than 700 papers from 37 countries, was certainly a memorable experience for acousticians from Europe and America as well as from Asia. The first WESPRAC (Western Pacific Regional Acoustics Conference) was held in Singapore in 1982, but removal of the "R" from the conference acronym now signifies that the conference is no longer regional but international. This conference also celebrated the 25th anniversary of the Acoustical Society of Korea, which now has nearly 3000 members.

Plenary lectures were given by Ronald Roy ("Better life through bubbles and biomedical ultrasound"), Sang-Chul Lee ("Korea's IT: A new social infrastructure") and Hideki Kawahara ("A precursor to ecologically relevant speech science"). Lee's lecture, which described the transformation of Korea into a connected society, was especially interesting as he described the "thumb people" and how their lives center around their cell phones, and pointed out how Korea has become the "IT test bed of the world."

The well-planned program also included opening and closing ceremonies, tutorials, exhibits, a welcoming reception, a banquet (with Korean music and dance), a session chairs' dinner, keynote lectures, invited and contributed papers, and poster sessions. Virtually every area of acoustics was represented on the program.

The next WESPAC will be in Beijing in 2010.

New ASA Fellows: Dajun Tang, Charles Salter, Gail ter Haar, Ralph Stephen, Shrikanth Narayanan, Donna Neff (vice-president), William Yost (president), Bertel Møhl, Alex Case, J. Gregory McDaniel, Sheryl Gracewski, Lee A. Miller, Carol Espy-Wilson.

Scanning the Journals

Thomas D. Rossing

• Two papers presented at the 2005 **Australian Acoustical Society** conference are reprinted in the December issue of *Acoustics Australia*. A paper entitled "Learning Acoustics through the Boundary Element Method: An Inexpensive Graphical Interface and Associated Tutorials" was awarded the President's Prize for the best technical paper. The Boundary Element Method (BEM), the paper points out, is particularly useful for analyzing sound radiation and acoustic scattering problems. The other paper "Acoustic Systems in Biology: From Insects to Elephants" discusses the physical principles in the sound production and hearing of a variety of creatures. The dominant frequencies used for communication by a large range of air-breathing animals is nearly proportional to the body mass raised to the -0.4 power.

• **Tunable nanoresonators** constructed from telescoping multiwalled carbon nanotubes (MWNTs) are described in the 2 June issue of *Physical Review Letters*. Such resonators, with their low masses, low force constants, and high resonant frequencies, are capable of weighing single bacteria, detecting single spins in magnetic resonance systems, and even probing quantum mechanics in macroscopic systems. In the device, a specially prepared MWNT is suspended between a stationary contact and a mobile piezo-controlled electrode. Varying the length of the nanotube beam through the controlled telescoping of the inner nanobtube core from the outer nanotube shell tunes its resonant frequency.

• Higher sound clarity is obtained in **classrooms** when sound diffusers are applied to rear walls and ceilings rather than side walls, according to a paper in the *Proceedings of WESPAC IX*. However, absorbers increase sound clarity even more effectively with smaller area in comparison with diffusers.

• A protein associated with a disorder that causes **deafness** and blindness may hold a key to one of the foremost mysteries of hearing, according to a paper in the June 28 issue of *Journal of Neuroscience*. Scientists have identified protocadherin-15 as a likely player in the conversion of sound into electrical signals. The findings will not only provide insight into how hearing takes place at the molecular level, but may also help us explain why some people temporarily lose their hearing after exposure to loud noise but regain it a day or two later. The protein is referred to as the "tip-link antigen" (TLA) because it induces the production of special antibodies which bind to the protein at the stereocilia tips in the cochlea. Using mass spectrometry, the researchers analyzed the makeup of the TLA and found two peptide sequences that match up to key segments of the protein protocadherin-15 in humans, mice and chickens.

• For any **touch, sound, or image** to be perceived, our senses have to activate neurons at the center of the brain, in the thalamus. According to a paper in the 16 June issue of *Science*, the weak neurons along the thalamocortical pathway may find strength through amplification within cortical layer 4. Researchers were able to measure excitatory electrical activity generated in a single cortical neuron in a mouse cortex by a single thalamic neuron.

• Several interesting effects are reported when **cavitation bubbles** are generated inside water drops in microgravity, according to a paper in the 1 September issue of *Physical Review Letters* (**97**, 094502). Toroidally collapsing bubbles generate two liquid jets escaping from the drop, and the "splash jet" discloses a remarkable broadening. Shock waves induce a strong form of secondary cavitation due to the particular shock wave confinement, which offers a way to estimate integral shock wave energies in isolated volumes. Bubble lifetimes in drops are shorter than in extended volumes in remarkable agreement with herein derived corrective terms for the Rayleigh-Plesset equation. These observations, made on board an aircraft flying in parabolic arcs to create near-weightless conditions, would be difficult, if not impossible, in normal gravity.

• A mathematical system for organizing the 12 **tones of the Western scale** that makes use of a topological structure called an orbifold is described in the 7 July issue of *Science*. Chords are points in the topological space, and the segments connecting them indicate how chords progress. The work described in this paper is part of an ambitious project to characterize musical composition in great generality by means of mathematical music theory.

• **Language** is largely symbolic, but how we say something can be as important as what we say, according to an article in the 21 July issue of *Science Now Daily News*. Twenty four college students were asked to describe a dot moving across a screen. The students were told to use one of two sentences: "It is going up" or "It is going down." The team found that when students described the dots going up, the pitch of their voice was, on average, 6 hertz higher than that of those describing the dot going down. The same thing happened when another 24 students read the sentences from a computer screen, indicating people change the sound of their voice according to directional information contained within words. Listeners readily caught these cues.

• To a person who suffers from **hyperacusis**, even the sound of their own voice can be intolerable, according to an article in the 15 July issue of *New Scientist*. Nobody knows exactly what causes hyperacusis, but it can be brought on by head injuries, exposure to extremely loud sounds, Lyme disease or autism. It has also been linked with tinnitus. The main question puzzling researchers is whether it results from structural damage to the ear or flaws in the way the brain interprets sound signals. The most successful treatment is a therapy using gradual desensitization with "pink noise," sound in which the amplitude decreases with increasing frequency.

• Two-way communication over gas pipelines using multicarrier **modulated sound waves** is the topic of a paper in the July issue of *Acoustical Science and Technology*. Conventional acoustic communication technology is limited by the effect of reverberant signals, but the use of multi-carrier frequencies which change cyclically avoids this. Using this method, a transmission rate of 3840 bps was achieved.

- A portable navigational aid for the blind transmits soft, **low-pitched beeps** directly to the inner ear, according to an article in the 19 August issue of *New Scientist*. The system guides users with beeps that appear to come from whatever direction the person needs to head in. The user simply walks towards the sound. The device uses a processor in a backpack to combine GPS location readings with data from cameras and motion sensors attached to a headband or helmet. This information is fed into a virtual 3D model of the streetscape or building the person is navigating to calculate which direction the person should walk. To make the beeps appear to come from a particular direction, the system varies the timing and intensity of the vibrations transmitted to each earpiece to vibrate the skull.
- The pattern of the **sound waves** viewed by the Wilkinson Microwave Anisotropy Probe satellite, which show the abundance of hydrogen and helium in the universe, are another evidence for the large amount of dark matter in the universe according to an article in the August 29 *Scientific American Newsletter* online. These measurements are in agreement with other measurements which show that at most, 5 percent of the mass-energy density of the universe is in the form of atoms. Many physicists and astronomers think dark matter is probably a new particle that so far has eluded detection during particle accelerator experiments or discovery among cosmic rays. In order to behave as dark matter, it must be heavy and weakly interacting with normal matter.
- The April issue of *Acoustics Australia* is a special issue on **Mechanisms of Hearing Damage**. The articles are presented in a "top down" order beginning with the psychoacoustics of sound localization using head-related transfer functions. Another article reviews neural organization with particular emphasis on the signals which descend to the cochlea to either control the processing of sound via the outer hair cells or the excitability of primary neurons carrying the frequency analysis upward. Two papers deal with the genetics of hearing loss. The special issue attempts to draw attention to the cross-fertilization between psychoacoustics and physiological acoustics.
- Taiwan's high-speed train, scheduled to open in October, has raised new questions about the level of **noise and vibration**, according to a story in the August issue of *IEEE Spectrum*. The latest twist in this tale began three years ago, when the government solicited design concepts for reducing vibration from passing bullet trains. Taipei-based Sheus Technologies Corp. proposed to stiffen the rail bed's foundation and install barrier walls containing elastic rubber pellets. However, the design is not predicted to meet the National Science Council's goal, which reportedly was to limit noise from a train passing 200 meters from the track at 300 kilometers per hour to 48 decibels. Some observers fear that semiconductor manufacturing in Tainan Industrial Park may be affected by the vibrations.
- "Our atmosphere is filled with sounds that we cannot hear," begins an article on **infrasound** in the August issue of *Physics World*. "From listening in on volcanoes to detecting nuclear explosions, a global network of infrasound detectors is allowing researchers to tune in to our atmosphere." Infrasound has been a hot topic in ASA recently, as readers of *JASA*, *Acoustics Today*, and *ECHOES* are well aware. "Infrasound" was the lead article in the January 2006 issue of *Acoustics Today*, as it was in the Fall 2001 and Fall 2005 issues of *ECHOES*. Although much of the same material is covered in this article, two items that caught my eye were the "mystery of the Earth's low-frequency hum," due to standing Rayleigh waves driven by atmospheric turbulence; and the new optical fiber infrasound sensors that get around the use of mechanical filters to reduce background noise. Unlike audible sound, infrasound can travel thousands of kilometers through the atmosphere and is used by some animals as a form of communication.
- According to a paper entitled "The failure of the Tacoma Bridge: A physical model" in the August issue of the *American Journal of Physics*, "one of the most surprising of physical phenomena is the conversion of a steady state condition into oscillations." Other examples of **self-excited oscillations** include the blowing of air through the reed of a clarinet, the flow of air over the embouchure hole of a flute, and the conversion of the steady pull of a violin bow into oscillation of the string. The paper addresses historical misconceptions of the 1941 Tacoma Narrows Bridge collapse, a computational model of vortex behavior, and evidence for the correctness of this model. Fluid mechanics has typically been the domain of experimentalists because the governing equations are difficult to solve. Only now, they point out, is computer power becoming equal to the task.
- "Zap-while-you-scan therapies set sights on cancer" is the title of an article in the August 12 issue of *New Scientist* describing the use of **high-intensity ultrasound** to kill tumors. The idea is to use magnetic resonance imaging (MRI) or computed tomography (CT) to create three-dimensional images precise enough to guide a tumor-zapping beam of ultrasound to its target. Surgeons can be confident they have hit all of the tumor and spared the surrounding tissue according to surgeons at the Ontario Cancer Institute in Toronto. The scanner can also measure real-time tissue temperature, so the doctor knows exactly when the target has received a sufficient dose.
- "Hearing colours, **seeing sounds**" in the 3 August issue of *Nature* is a commentary on Kandinsky's synaesthetic paintings. Reacting to a performance of Wagner's opera "Lohengrin," the Russian painter conceived a kind of painting that might aspire to the abstract condition of music. Attempts to devise color notations for music date back to

the sixteenth century, and the earliest attempt to construct a color organ was made as long ago as the early eighteenth century. Kandinsky considered color as the "keyboard, the eyes are the hammers, the soul is the piano with many strings." In 1914 he painted "Fugue," whose interwoven sequences of colored patterns are explicit representations of musical motifs.

• Physicists in the US and Japan have found strong evidence that **phonons** play a key role in high-temperature superconductivity, according to a letter in the 3 August issue of *Nature*. The phonons allow electrons with opposite spins to pair up, which is widely believe to be what happens in conventional low-temperature superconductors, but until now no boson-mediated electron pairing has been observed in high-temperature superconductors. The paired electrons form bosons as they collapse into a single quantum state via a process called Bose-Einstein condensation. By placing the tiny metal tip of a scanning tunneling microscope above the surface of a bismuth strontium calcium copper-oxide (BSCCO) sample, the researchers measured the energy states in the superconductor on an atomic scale. Changes in current as the tip moved just a few nanometers across the sample indicate that the electron-pairing mechanism varies on these tiny scales, and that there is interplay between the paired up electrons and the crystal lattice.

• A discussion of **vibration isolation** of precision objects appears in the July issue of *Sound and Vbration*. The use of "smart" constant natural frequency (CNF) isolators substantially widens the application range of inexpensive passive isolators, which are generally less expensive than active isolation systems. CNF isolators have their stiffness proportional to the applied weight load in order to automatically satisfy decoupling conditions.

• According to an article in the September-October issue of *American Scientist*, some tadpoles hatch prematurely upon sensing a predator's **vibrations**. The red-eyed tree frog, an inhabitant of Central American tropical forests, lays clutches of eggs on leaves overhanging ponds, so that when the tadpoles hatch they drop into the water. The usual gestation period is six to eight days, but after four days of gestation the tadpoles will start to hatch if the clutch is attacked by a predator. The eggs apparently sense vibrations as a snake or other predator tears into the clutch. In the laboratory, the highest rate of hatching was induced by signals that had a half-second duration and intervals of 1.5 to 2.5 seconds, which are consistent with snake attacks.

• At terahertz frequencies, light couples with periodic lattice distortions resulting in **phonon-polaritons**, according to a letter in the 10 August issue of issue of *Nature*. Polaritons are electro-mechanical excitations in condensed matter that describe light propagation near resonances. In ferroelectric materials, terahertz radiation propagates by driving infrared-active lattice vibrations, resulting in phonon-polaritron waves. The resulting fast motion of these charges has been observed by using femtosecond X-ray diffraction.

• An **ultrasonic device** could help athletes who have had their teeth broken while playing high impact sports, according to a note in the 8 July issue of *New Scientist*. A piezolectric crystal generates low-power ultrasound at about 20 kHz applied to a tooth brace attached to the damaged tooth.

Café Acoustique?

Thomas D. Rossing

Café Scientifique meetings are popping up throughout the country, on campuses, in coffee shops, bars, and even a church, according to a story in the February 21 issue of *The New York Times*. Their purpose is to make science accessible and even fun to anyone with the time to stop by. The largest in the country to date is thought to be the Denver Café Scientifique, established in 2003, which draws about 150 people. The topics vary from sleep to interstellar communication to Higgs bosons to nanotechnology, according to the story, and they attract people of all ages and all occupations.

Acoustics is a scientific discipline with broad public appeal. Shouldn't we try to appeal to the public by establishing Café Acoustique meetings around the country? Perhaps some local ASA chapters already have done this, and if so I hope they will share their experiences with the rest of us. Perhaps such an event could be incorporated into ASA meetings. It's worth a try.

Apparently the café scientifique idea came from Leeds, England, where a note was posted in a bar saying "Where for the price of a cup of coffee or a glass of wine, anyone can come to discuss the scientific ideas and developments which are changing our lives." Café Scientifiques (www.cafescientifique.org) in Britain received public financing to get started, and dozens are now held around the country. In the United States most cafes have no budgets and are independent, although science cafes in Syracuse, NY and New York City charge a nominal fee. Sigma Xi, the scientific research society, was host to the first national gathering of Café Scientifique leaders in North Carolina in February to network and organize the movement.

Acoustics in the news

• Researchers at the University of Illinois and the University of Missouri-Rolla have built an ultrasound version of a laser, according to a story in the June 12 issue of *NASA Tech Briefs*. Called a uaser (pronounced WAY-ser for ultrasound amplification by stimulated emission of radiation), the instrument produces ultrasonic waves that are coherent and of one frequency. The device consists of piezoelectric auto-oscillators mounted on a block of aluminum, which serves as an elastic acoustic resonator. When an external acoustic source is applied, the oscillators synchronize to the frequency of the source. The device demonstrates, according to the inventors, that "the essential nature of a laser can be mimicked by classical mechanics–not quantum mechanics–in sound instead of light."

• It is now possible to hear what the voice of the Mona Lisa would have sounded like, according to a story in *CNN.com* dated June 2. The chart of any individual's voice, known as a voice print, is unique to that person, and a Japanese researcher believes he has achieved 90 percent accuracy in recreating the quality of the enigmatic woman's speaking tone. In the Mona Lisa's case, the lower part of her face is quite wide (which suggests a low voice) and her chin is pointed (which adds tones in mid-frequency).

• When it came out in December, the high-frequency sound of a device called Mosquito was supposed to be the sonic equivalent of a "no loitering" sign (see Acoustics in the News in the summer issue of *ECHOES*). Its annoying sound, which many adults can't hear but most young people can, would act as a teen repellent. Now, according to a story in the June 14 issue of *The Washington Post*, teens are getting back at adults. Downloading the sound, or another ring tone in the same frequency range (around 17 kHz), allows them to hear their cellphones ring when their parents and teachers cannot. Traffic at one website which markets the tone, spiked as 100,000 kids tried to download the sound.

• "Balancing the art and science of sound" is the title of an article in the advertising supplement to the June 14 edition of *International Herald Tribune* that deals with opera houses. "It's a myth that there's a perfect acoustics" is a statement by an opera conductor with which many acousticians would agree. However, the definition of acoustics as "basically air vibrating in a cavity" is one with which there would be less agreement.

• Last year, according to the 11 July issue of the *Institute*, more than 1500 people joined the IEEE Women in Engineering (WIE) group, the largest annual growth in its history, bringing the total number of WIE members to about 12 000. Last year also saw the formation of 43 WIE Affinity Groups and Student Affinity Groups, the most ever established in one year, for a total of 103. Student IEEE membership increased by more than 8% last year, while membership in regular grades increased only 0.5%.

• Scientists at the University of Tromso in Norway are investigating the "strange musical sounds" practiced by violinist Mari Kimura, according to a story in the 6 July issue of the *World Science* home page. ASA members may recall that Roger Hanson and Fred Halgedahl explained these "anomalous low frequency" (ALF) violin sounds some 15 years ago, and Mari demonstrated them at an ASA meeting.

• A $30 million Air Force memorial just west of the Pentagon which reaches 300 feet into the air required a special vibration damper, according to a story in the 17 July issue of the *Washington Post*. Early in the design process, wind-tunnel tests revealed that the wind could send the silver spires into a series of oscillations that could lead to catastrophic failure. The solution involved an exotic trick of physics. Hidden high inside the elegant metallic spires designed by James Ingo Freed, who also designed Washington's Holocaust Museum, are 13 steel boxes, a stack of six in the tallest spire, four in the next and three in the last, which, although it is the shortest, still rises 201 feet above the ground. The boxes are about 2 1/2 feet on each side, and each contains a single, free-rolling, metal ball that is 20 inches in diameter and weighs nearly a ton. Those balls in boxes provide a unique energy-damping system that, although invisible to visitors, promises to keep the monument's swaying within tolerable limits well into the 22nd century.

• Although the world seems to get noisier all the time, the hearing of Americans is not worse today than it was 35 years ago, according to a government study reported in the 30 June issue of *Science*. The study of some 5000 subjects reports that blacks have better hearing than whites, and women hear better than men.

• A dark horse has jumped into the race to solve the mystery of dark energy, according to a story in the August 12 issue of *New Scientist*. NASA has decided to fund the ADEPT probe, which will probe this unknown force by looking for the imprint of primordial sound waves. Until now, the front runners were missions that planned to study dark energy by looking for ancient supernovae, which is hardly surprising, since it was the study of supernovae in the 1990s that led to the discovery of dark energy. The ADEPT (Advanced Dark Energy Physics Telescope) probe, however, will look for sound waves that permeated the infant cosmos and helped to trigger the formation of galaxies. Astronomers have noted a repeating pattern of slight excesses of galaxies in the cosmos having a wavelength of a few 100 million light years.

• It's a myth that there is a perfect acoustic," Kent Nagano, the new music director at Munich's Bayerische Staatsoper, is quoted as saying in the June 14 issue of the *International Herald Tribune*. Nagano, who succeeded Zubin Mehta, considers the Munich opera house to be "fantastic" for opera but not for symphonic concerts. When the orchestra leaves the pit to go onstage a specially designed acoustic shell is employed. Nagano says that the only way to know what the audience hears is by going into the seats oneself.

• Wavelets are being used to transform the haunting calls of whales into movies, according to a story in the August 1 issue of *The New York Times*. According to engineer Mark Fischer, who learned about acoustics by developing software for Navy sonar, the images capture intricate details in the whale sounds that are not easily heard. Wavelets are capable of picking up auditory fingerprints that are unique to different species and even individuals within a group (see article on whale vocalization in the Summer 2006 issue of *ECHOES*). Some of the whale images can be viewed at http://www.neoimages.net/artistportfolio.aspx?pid=1270.

- The builders of the new organ in the Kimmel Center in Philadelphia call it the largest pipe organ in any concert hall in the United States, according to a story in the May 15 issue of *The New York Times*. The organ, built by Dobson Pipe Organ Builders of Lake City, Iowa, has 125 ranks with 6,938 pipes, some more than 40 feet in length. Oliver Latry, the organist at Notre Dame in Paris, who performed during the two-week opening festival, described the organ as "wonderfully versatile."
- Flying mosquitoes may change the whining tone created by their wings to match those of potential mates, according to a note in the July issue of *Current Biology*. Researchers recorded the wingbeat frequencies of pairs of tethered tropical mosquitoes and found that both mosquitoes in an opposite-sex pair alter their wingbeat patterns until their flight tones are the same. By contrast, the noises made by same-sex pairs diverge in frequency. Males, who have more sensitive antennae, make wingbeat adjustments more quickly than female mosquitoes.
- Particle physicists have come up with a novel way to promote free, immediate access to journal articles, according to a note in the 1 September issue of *Science*. Led by CERN, the giant lab near Geneva, Switzerland, they propose to raise at least $6 million a year to buy open access to all published papers in their field. Recently, the American Physical Society announced that a $975 to $1300 payment to its two main journals would make an article available to all readers. Elsevier, the other major particle physics publisher, announced an open-access option for $3000. Nearly all particle physicists already share preprints of their articles on free servers such as arXiv.org at Cornell University, but the final article is still what academia values most.
- While most members of Congress are back home campaigning for reelection, according to a story in the 18 August issue of *Science*, a small group of staffers is at work in Washington on legislation that could influence science spending for years to come. Their goal is to craft a broad bill aimed at bolstering U.S. competitiveness that Congress could pass before the November election. The legislation draws upon several reports published over the past year, including the National Academies' *Rising Above the Gathering Storm*. Unlike appropriation bills, which determine how much each federal agency can spend in a given year, these bills set desired funding levels over several years and attempt to draw political support for ongoing spending increases.

Letter from the Editor: A new look

ECHOES has a new look—sort of. It is now the Online Newsletter of ASA, which will appear on the ASA website while the news is fresh and will later be reprinted in *Acoustics Today*. This change, which Editor-in-Chief Allan Pierce proposed and the Executive Committee approved, should serve the best interests of ASA members and other readers.

Since the "marriage" of *ECHOES* with *Acoustics Today*, we have experienced some timing problems. Being a magazine, *Acoustics Today* has a fairly long production schedule, which tends to detract from the value of a newsletter. The time from submission of *ECHOES* news material to publication was running 4 to 5 months, and some of the news was pretty old by the time it was read.

The new combination of an online newsletter, later reprinted in a magazine, is not unlike the relationship of *JASA-EL* and *JASA*, which has worked out well. ASA will send a reminder to the members soon after a new issue of *ECHOES* is posted online, which should be about 6 weeks before and 6 weeks after each ASA meeting, but readers should watch the ASA website. Deadlines for submissions to *ECHOES* will revert back to the old schedule: 2 months before and 1 month after each ASA meeting. We welcome your comments as well as your submissio, of course.