Session 5aAA

Architectural Acoustics: Architectural Acoustics Potpourri

Russell N. Altermatt, Chair
Altermatt Associates Inc., 522 SW Fifth Ave., Suite 1200, Portland, OR 97204

Contributed Papers

8:00

5aAA1. An application of the finite difference time-domain method to the study of coupled volumes. Jonathan M. Botts and Ning Xiang (Program in Architectural Acoust., Rensselaer Polytechnic Inst., 110 8th St., Troy, NY 12180, bottsj@rpi.edu)

A finite difference time domain (FDTD) scheme is applied to study the behavior of sound energy decay in coupled-volume systems. This particular method takes into account frequency dependent wall impedance as well as source characteristics. In time-domain method, impulse responses are direct results of numerical calculation and transient effects specific to coupled volumes can be visualized. In addition to examining traditional acoustic metrics, this model allows for the investigation of the sound energy flows in the system. The numerical calculations will also be compared with experimental scale model measurements. Though limited to low frequencies due to computational load, this method will demonstrate many advantages over geometric acoustic models and other wave based models for the study of coupled volumes.

8:15

5aAA2. One-dimensional transport equation models for sound energy propagation in long spaces. Yun Jing (Graduate Program in Architectural Acoust., Sch. of Architecture, Rensselaer Polytechnic Inst., Troy, NY 12180), Edward Larsen (Univ. of Michigan, Ann Arbor, MI 48109), and Ning Xiang (Rensselaer Polytech. Inst., Troy, NY 12180)

In this paper, a three-dimensional transport equation model is first presented to describe the sound energy propagation in a long space. Then the three-dimensional model is reduced to a one-dimensional model by approximating the solution using the method of weighted residuals. The one-dimensional transport equation model directly describes the sound energy propagation in the long dimension and deals with the sound energy across the cross-section by prescribed functions. The one-dimensional transport equation model consists of a coupled set of N transport equations. Only $N = 1$ and $N = 2$ are discussed in this paper. For larger N, although the accuracy could be improved, the calculation time is expected to be significantly longer, which diminishes the advantage of the one-dimensional model over the three-dimensional model in terms of the computational efficiency. Some simulation results are provided in comparison with the ray-tracing based approach, which show good agreement.

8:30

5aAA3. Reciprocal maximum-length and related sequences in the generation of natural, spatial sounding reverberation. Uday Trivedi, Eric Dieckman, and Ning Xiang (Graduate Prog. in Architectural Acoust., School of Architecture, Rensseleaer Polytechnic Inst., Troy, NY 12180, triveu@rpi.edu)

The development of artificial reverberation has made considerable progress in recent years. In this research, a unique approach utilizing reciprocal maximum-length sequences and related sequences is taken in generating a natural, spatial sounding reverberation. Additionally, an algorithm to shape and vary spaciousness within the context of an artificially generated reverberation is implemented. Results are verified through experimental measurements and subjective testing methods in a multichannel format. This work sheds light on alternative methods of generating artificial reverberation outside of commercially available systems. As a result, a direct application to room modeling techniques can be drawn with this work. Extensions of this research will comprise of investigations in objective and subjective behaviors of double-sloped energy decays in acoustically coupled spaces. From an educational perspective, outcomes of this research can serve as a foundation in ear-training for acoustics students seeking a broadened understanding of perceived reverberation in varying contexts.

8:45

5aAA4. Optimized overdetermination for interior Helmholtz problem coupled solvers. Alexander Bockman, Paul Calamia, and Ning Xiang (Dept. of Architectural Acoust., RPI, 110 8th St., Troy, NY 12180, bockma@rpi.edu)

The use of points of overdetermination, so-called CHIEF points, in numerical solutions to exterior Helmholtz problems for the elimination of spurious modes is well established. Further, the number and relative position of such points in two-dimensional radially symmetric geometries has been demonstrated theoretically. Since CHIEF points require lower computational overhead than collocation nodes, strategic use represents an opportunity for the improvement of predictions with maximal efficiency. Given the differing uniqueness properties of solutions to the interior and exterior problems, the former allows for development of optimization in the absence of competing priorities. Theory for two- and three-dimensional analytical cases is developed and subsequently extended to general geometries. Localization with respect to subdomains of spatial decomposition is investigated as well.

5a FRI. AM

9:00

5aAA5. Evaluation of the newly developed equation for noise barrier within an enclosed space. Lau Siu-Kit (Archit. Eng. Prog., 203C Peter Kiewit Inst., Univ. of Nebraska-Lincoln, 1110 South 67th St., Omaha, NE 68182-0681, sklau@engineer.com and) and Kwok-Wai Lam (The Hong Kong Polytechnic Univ., Hung Hom, Kowloon, Hong Kong)

Indoor barrier can be employed to ensure the privacy of speech in open-plan offices and to shield the noise generated by the machines in plant rooms. However, existing publications on diffraction and noise reduction by barrier inside an enclosed space using the classical theory is limited by the assumption of diffuse field. Recently, a new formula for estimating the barrier insertion loss inside an enclosed space was proposed by Lau and Tang [J. Sound Vib. **20**, 50–57 (2009)]. It is simple and is sufficiently accurate in engineering practice. In the present study, this new formula is proposed to estimate the insertion loss of a vertical partition between two flat rooms. The performance of the new formula is compared with that of the classical diffuse-field theory. The results indicate that the new formula provides more realistic and practical predictions of the insertion loss of the partition between two flat rooms than existing approaches. [The work described in this paper was supported by a grant from the Hong Kong Polytechnic University (Project A/C code: G-U362).]

9:15

5aAA6. Design and testing of a variable acoustics production studio with reflection free zone control room. Jon Mooney, Seth Harrison (KJWW Eng. Consultants, 623 26th Ave., Rock Island, IL 61201, mooneyjw@kjww.com), and Jon Brennan (Curtis, Inc., Cincinnati, OH 45203)

The new home of Curtis, Inc. in Cincinnati, OH, includes a recording studio and control room designed and tested by KJWW Engineering Consultants. The recording studio features adjustable wall treatments, which may be opened in varying degrees to adjust absorption and diffusion within the room. The adjoining control room has been designed to position the recording engineer inside a reflection free zone (RFZ). This design directs speaker reflections from the front of the room away from the recording engineer, extending the initial time delay (ITD) without requiring a dead front end. The control room also features unique wall and ceiling treatments, which serve not only as variable binary diffusers and absorbers but also as storage cabinets. These design elements allow for broad adjustment of the control room acoustics. The configurable design of the recording studio and control room coupled with exceptional sound isolation enable this facility to create flexible recording and listening environments. This paper will present an overview of: 1. The recording studio and control room designs; 2. The changes required during construction and their effects; 3. Acoustical measurements, quantifying the variable response of the rooms; 4. Operation of the rooms and preferred settings.

9:30

5aAA7. The acoustic shell of the Plaza de La Fe in Managua, Nicaragua. Russ Altermatt (Altermatt Assoc., Inc., 522 SW 5th Ave., S-1200, Portland, OR 97204)

The Plaza de La Fe, the Plaza to the Faith, of Pope John Paul II, in Managua, Nicaragua, is the site of many celebrations for the people of Nicaragua. At one end of the plaza, a performance, acoustic shell was constructed as a focus for performances in the plaza. The acoustic shell has a very large capacity, for full orchestra and choir, at a minimum. It supports multiple band setups on the same stage depending on the celebration requirements. The shell is used for all types of performances and presentations, be they multiband, dance, classical music, or speech. In spite of significant concavity of the overall design, the shell elements were also molded to provide directional sound reflections both to the plaza and to the performers on the stage. This presentation will show the progress of the project from design, through construction. The acoustic shell was inaugurated with an attendance of over 100,000 in Jan. 2005.

9:45

5aAA8. Classroom sound systems: Not a Green substitute for proper classroom acoustics. Richard F. Riedel (Riedel Audio & Acoust., 443 Potter Blvd., Brightwaters, NY 11718, riedelaudio@optonline.net)

The author will discuss the negative environmental impact that individual classroom sound systems create when used as a substitute for good acoustical design. School systems are being targeted by marketers of classroom sound systems and being convinced that they are a cost effective alternative to the standards that are put forth by ANSI S12.60-2002. This paper presents estimates of the potential waste that is created by these systems through future disposal of outdated technology and batteries used in these devices. The presentation will put forth suggestions for the dissemination of this information by interested parties to schools in their immediate vicinity.

10:00

5aAA9. Did paleolithic cave artists choose resonant locations for paintings? David Lubman (DL Acoust., 14301 Middletown Ln., Westminster, CA 92683, dlubman@dlacoustics.com)

Paleolithic artists were surely impressed by the acoustical properties of their cave dwellings. Since many inhabited caves and grottoes were highly reverberant, it is compelling to speculate that cave acoustics importantly influenced ancient artists. One imaginative suggestion is that Paleolithic artists intentionally chose the most resonant locations for painting. This thesis was proposed by Iegor Reznikoff and Michel Dauvois in the Bulletin de Ia Societe Prehistonque Francaise **85**, 238–246 (1988) and was engagingly described by British archaeologist Chris Scarre ["Painting by resonance," Nature (London) **338**, 382 (1989)]. Scarre found this thesis consistent with "the likely importance of music and singing in the rituals of our early ancestors." The researchers found a greater density of paintings where sonic resonances were judged strongest. However, that finding may be spurious: the same result is predictable from painterly rather than sonic considerations. Painters would likely choose nonporous rather than porous rocks to conserve pigment. Since nonporous rocks are generally highly sound reflective, nonporous rock locations tend to be highly resonant. Since porous rocks tend to absorb sound, porous rock locations are less resonant. Thus the higher density of cave paintings found at resonant locations may not imply the artists' preference for resonance.

10:15

5aAA10. Tehran concert hall—a virtual specimen indicative the conversion processes from architectural design to acoustical remedies. H. Azad (Dept. of Architecture, Camp. of Fine Arts, Univ. of Tehran, Enghelab st. Tehran, Iran, hassan.azad@gmail.com)

Over the last year of the B.Sc. period it was investigated by the author to design a 1200-seat concert hall as the thesis project. Now the quoted project has been enriched by the acoustical aspects of the concert hall design regarding the acquired capabilities during the M.Sc. studies. It has become prevalent these days to peruse and analyze the acoustical parameters of enclosures through the different acoustical simulation software such as Odeon 9, CATT-Acoustics 8, EASE 4.1, and Ramsete 2.5, either before or after their construction as an objective assessment but interpreting this data is a real challenge. [H. Azad. "Ali Qapu: Persian Historical Music Room?". Auditorium Acoustics Conference (2008), Oslo.] The variable height stage canopies taking into account their shape and materials is investigated by calculations with ray-tracing computer model to provide a large part of the audience with early reflections and to create good ensemble conditions for the musicians on stage. The diffusers design as a geometrical shape with design factors of height, surface coverage and orientation in addition to their location will be studied computer aided to improve the acoustics in this virtual concert halls.

Session 5aAB

Animal Bioacoustics and Signal Processing in Acoustics: Signal Processing Techniques for Subtle or Complex Acoustic Features of Animal Calls

Ann E. Bowles, Chair
Hubbs Sea World Research Inst., 2595 Ingraham St, San Diego, CA 92109

Chair's Introduction—7:30

Invited Papers

7:35

5aAB1. Distinguishing FM-modulated bowhead whale calls from airgun and other biologic signals using image processing, feature extraction, and neural networks. Aaron Thode, Delphine Mathias (Marine Physical Lab., Scripps Inst. of Oceanogr., 9500 Gilman Dr., San Diego, CA 92109-0238), Susanna Blackwell, Katherine Kim, and Charles Greene, Jr. (Greeneridge Sci. Inc., Goleta, CA 93117)

The detection and identification of repetitive or stereotyped bioacoustic signals in raw acoustic data are typically accomplished via matched filtering or spectrogram correlation techniques. However, the detection of FM-modulated sweeps that have variable frequency-modulated contours or bandwidths is still an active challenge. The problem is made more complex by the possible presence of other frequency-modulated signals such as airguns or other biologics. To provide a specific example, in 2007 and 2008 directional autonomous recording packages (DASARs) were deployed in the Beaufort Sea to monitor the annual migration of the bowhead whale (*Balaena mysticetus*) population during seismic exploration activities. A portion of these data sets has been manually analyzed, providing an opportunity to characterize the miss and false alarm rates of various FM-modulated detection and classification methods. Here literature and software on bioacoustic FM-contour tracing and classification are reviewed, with a particular emphasis on the use of contour tracing, image segmentation, feature extraction, and neural networks for identifying species-distinctive sounds. A combination of these methods, when applied to the Arctic data set, has been found to reduce the false alarm rate by a factor of 5, while preserving a miss rate of less than 20%. [Work supported by Shell Oil Co.].

7:55

5aAB2. A graph search algorithm for delphinid whistle contours. Marie A. Roch, Bhavesh Patel (Dept. of Comp. Sci., San Diego State Univ., 5500 Campanile Dr., San Diego, CA 92182-7720), Melissa S. Soldevilla, and John A. Hildebrand (Scripps Inst. of Oceanogr., Univ. of California, San Diego, La Jolla, CA 92093-0205)

A graph search algorithm is presented to extract tonal contours from audio signals in a fully automated manner. The algorithm is capable of tracking multiple contours simultaneously. Search is done in the spectral domain, with contours being treated as paths through a phase-magnitude space. A graph search formalism is combined with dynamic programming techniques to track candidate paths that may overlap or cross. Disambiguation of path crossings is accomplished by examining a combination of slope and the derivative of phase. The algorithm is general in nature and applicable to tonal calls from many animals with little modification. We target this work specifically toward delphinid whistles and demonstrate its efficacy on calls from bottlenose (*Tursiops truncatus*), short- and long-beaked common (*Delphinus delphis* and *D. capensis*), and Risso's (*Grampus griseus*) dolphins recorded in the Southern California Bight. Characterizing the complete contour will permit the development of call comparison techniques that take into account finer grained detail than the typically used contour statistics (e.g., number of inflection points, minimum, and maximum frequencies). [This work is sponsored by the Office of Naval Research.]

8:15

5aAB3. Noise-resistant acoustic measurements implemented in user-friendly software. David K. Mellinger (Cooperative Inst. for Marine Resources Studies, Oregon State Univ. and NOAA Pacific Marine Environ. Lab., 2030 SE Marine Sci. Dr., Newport, OR 97365)

Searching for vocalizations in lengthy marine recordings can be significantly enhanced by annotations indicating times, frequencies, and other characteristics of calls. Defining optimal search features, however, is difficult. For instance, one may wish to find harbor seal "roar" vocalizations, which extend up to 6 kHz, last 3–10 s, and have a broadband, non-tonal sound quality. What features best characterize such sounds? Marine recordings often contain vocalizations recorded at low signal-to-noise ratios, and it is essential that call measurements be consistent across different background noise levels. For instance, bandwidth is traditionally measured by manually indicating lower and upper frequency bounds in a spectrogram, and then subtracting the two. However, for vocalizations that fade at higher frequencies, like harbor seal roars, such bandwidth measurements can vary by a factor of three from low-noise to high-noise environments. Here we describe measurements, based principally on Fristrup's "Acoustat" approach, that have consistent values at variable noise levels. For instance, bandwidth is measured as the standard deviation of frequency, weighted by the per-frequency-bin normalized intensity. A set of noise-robust measurements have been implemented, including measures for duration, amplitude and frequency modulation, and many others. Implementation of these measurements in easy-to-use Ishmael and MATLAB software is described.

8:35

5aAB4. Signal processing challenges in the analysis of stereotyped killer whale calls produced in social contexts. Ann E. Bowles (Hubbs-SeaWorld Res. Inst., 2595 Ingraham St., San Diego, CA 92109, abowles@hswri.com), Jessica L. Crance, and Juliette S. Nash (Univ. of San Diego, San Diego, CA 92108)

Research on call development and usage by individual killer whales has been limited by signal processing challenges, which include (1) more than one simultaneously operating source, (2) a pulse-burst production mechanism, (3) a complex repertoire (7–17 calls), (4) gradation with nonstereotyped call types, (5) presence of nonstereotyped features encoding state (e.g., arousal), and (6) vocal matching among callers. To date, the most successful signal processing efforts have targeted tonal, modulated "screams." However, analysis of other component types (bursts, resting call), parsing of calls into components, and reliable classification of calls continue to require the intervention of a human brain. Under controlled laboratory conditions, using data from seven whales at SeaWorld San Diego, these characteristics were analyzed by ear and using traditional statistical methods. The work showed that important insights could be gained by comparing these call characteristics among individuals and social contexts. However, estimates of the sample sizes needed to show significant differences among individuals suggest that automation will be essential. Use of the human ear as a signal processor could also introduce biases. Efficient automation would greatly improve the study of individual call usage. [Work supported by the Hubbs-SeaWorld Society and SeaWorld San Diego.]

8:55

5aAB5. Feature vector selection for identifying killer whale individuals. Nicole Nichols, Les Atlas (Dept. of Elect. Eng., Univ. of Washington, Box 352500, Seattle, WA 98195, nmn3@u.washington.edu), and Ann Bowles (Hubbs-Seaworld Res. Inst., San Diego, CA 92109)

One hindrance to studying whales is the simple act of identifying individuals. The source filter model of human speech is a potentially useful model for killer whale vocalizations. With this assumption, evaluation of vocal model based optimizations for human speaker recognition was performed with a whale dataset. (Twenty one calls of type 1a or 1b, from four captive Icelandic killer whales.) Feature vectors were extracted from sound samples, which reduce dimensionality while encapsulating the identifying characteristics. Recognition accuracy is highly dependent on choosing a feature vector, which can accurately divide the sample space. Cepstral coefficients are the standard used for human speaker recognition. Modulation envelopes are known to be important for perception and have been shown to improve speech recognition performance [Kingsbury *et al.*, Speech Commun. **25**, 117–132 (1998)]. Modulation spectrograms were examined and sampled across acoustic frequency at the fundamental modulation rate of the call to extract modulation feature vectors. Visual analysis of modulation spectrograms note a possible pattern unique to individual whales. Presented herein is analysis of these patterns based on linear discriminant functions and hidden Markov models. [Work supported by National Science Foundation Graduate Research Fellowship, University of Washington, Hubbs-Seaworld Research Institute.]

Contributed Papers

9:15

5aAB6. Rhythmic analysis of sperm whale broadband acoustic signals. Natalia Sidorovskaia, Philip Schexnayder (Dept. of Phys., Univ. of Louisiana at Lafayette, UL Box 44210, Lafayette, LA 70504-4210, nas@louisiana.edu), Alexander Ekimov, James Sabatier (Natl. Ctr. for Phys. Acoust., University, MS 38677), George E. Ioup, and Juliette W. Ioup (Univ. of New Orleans, New Orleans, LA 70148)

Rhythmic analysis of sperm whale clicks, based on the static Fourier transform, was previously reported in the literature as a tool for extracting the acoustic signature of individual sperm whales [Andre and Kamminga, J. Mar. Biol. Ass. U.K. (2000)]. A new approach, originated from the algorithm developed for human motion analysis [Sabatier and Ekimov, "A Review of Human Signatures in Urban Environments Using Seismic and Acoustic Methods," Proc. IEEE (2008)], is applied to study time-dependent periodicity in sperm whale signals recorded in the Gulf of Mexico. The new approach for rhythmic analysis of sperm whales clicks, which are used for navigation purposes, shows the presence of stable temporal periodicity that could possibly be attributed to the acoustic portrait of individuals. [Research supported in part by SPAWAR.]

9:30

5aAB7. Sei whale localization and vocalization frequency sweep rate estimation during the New Jersey Shallow Water 2006 experiment. Arthur E. Newhall, Ying-Tsong Lin, James F. Lynch, and Mark F. Baumgartner (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543, anewhall@whoi.edu)

The Shallow Water 2006 (SW06) experiment was conducted in the Mid-Atlantic continental shelf off the New Jersey coast. A fast-sampling, 48-channel hydrophone array system recorded a number of sei whale (*Balaenoptera borealis*) vocalizations during this time. This system had 16 hydrophones on the vertical line array (VLA) component covering the water column from 13-m depth to the bottom (80 m) and 32 hydrophones on the 480-m horizontal line array (HLA) component that lay on the bottom. The sei whale receptions on the arrays are low-frequency (less then 100 Hz) downsweep chirps and have the typical acoustic modal arrival pattern seen in shallow-water, low-frequency sound propagation. Due to acoustic modal dispersion, the frequency sweep durations observed from the receptions are found to be longer than the original signal. A horizontal beamforming technique using the HLA component is implemented to determine the bearings to whales. The whale location along the determined bearing and the frequency sweep rate of original whale sound are simultaneously estimated using the VLA component with a multiple-parameter optimization technique. This optimization technique is based on acoustic normal mode theory and is designed to compensate for the effect of acoustic modal dispersion.

9:45—9:55 Break

Chair's Introduction—9:55–10:00

Invited Papers

10:00

5aAB8. The challenge of nonlinear dynamics in understanding mammalian vocalization. Michael J. Owren (Dept. of Psych., Georgia State Univ., PO Box 5010, Atlanta, GA 30302-5010, owren@gsu.edu)

Recent advances in vocal-fold physiology have shown that nonlinear dynamics play a central, but largely unexplored role in mammalian vocalization. Understanding that role is crucial to coming to grips with vocal signaling as a form of communication, as the "nonlinear phenomena" associated with coupled-oscillator systems like the larynx strongly shape their acoustic output. Those acoustics in turn are necessarily central to understanding both signaler and perceiver roles in the communication process. Issues that are fundamentally affected by the nonlinear nature of mammalian vocalization include categorizing sounds in acoustics and perception, breaking a repertoire into constituent call-types, understanding the identity cuing potential of various sound-types, and the relative roles of cognition and emotion in vocal production and perception. However, progress is being impeded by a general lack of accessible, quantitatively based, and objective tools to help in detecting, identifying, and measuring nonlinear phenomena in vocalizations. So far, researchers trying to include such events in their analyses have been limited to visual inspection of spectrograms, subjective classification, and simple counting. A pressing need thus exists for development of accessible, yet necessarily rather sophisticated tools for use in identifying and measuring occurrences of nonlinear phenomena in mammalian vocal acoustics.

10:20

5aAB9. Quantifying noise in animal acoustic signals. Tobias Riede (Dept. of Biology, Univ. of Utah, 257 S 1400 E, Salt Lake City, UT 84112, t.riede@utah.edu)

Variability in noisy calls or call segments is often difficult to quantify but critical in order to understand animal acoustic communication. Such components represent a large proportion of animal acoustic signals and they are behaviorally meaningful. Such elements have also collectively been labeled as nonlinear phenomena. Three approaches are reviewed. The harmonics-to-noise ratio (HNR) can be related to perceptual characteristics of an acoustic signal as well as to the mechanism of its production. The HNR seems to be a useful numeric parameter to quantify vocal variability. Two problems with the procedure will be outlined. The nonlinear measure (NLM) is designed to provide an overall estimate of the strength of nonlinearity in a signal. The rationale is that if signal noise reflects low-dimensional chaos as produced through nonlinear processes, deterministic-nonlinear modeling will produce a relatively small error component. A stochastic linear model, on the other hand, will produce a relatively large error component when applied to such signals. In a third approach, utterances can be segmented in the temporal domain into harmonic and noisy components for separate analyses. Noise-specific procedures are used to analyze nonlinear phenomena. Advantages and disadvantageous of all three procedures are exemplified with sounds from mammals and anurans.

10:40

5aAB10. Parametric and holistic approaches to analyzing primate vocal signals for acoustic markers of caller identity, emotional state, and external context. Drew Rendall and John Vokey (Dept. of Psychol., Univ. of Lethbridge, Lethbridge, AB T1K3M4, Canada)

Vocal signals can be acoustically differentiated according to a variety of intrinsic and extrinsic dimensions. Among the most commonly investigated sources of signal differentiation in primates are those that mark the identity of the caller, potential variation in the caller's underlying emotional or motivational state, and external environmental factors associated with signaling (e.g., the presense of predators or food). We analyzed a corpus of grunt vocalizations recorded from wild baboons for acoustic cues associated with these three dimensions. Grunts were collected from eight adult female baboons in two different behavioral contexts: 1. When approaching other females to handle their infants, and; 2. When embarking on an extended foraging excursion. Both contexts were further subdivided into conditions associated with low- versus high-arousal for callers. Analysis of the signals involved two different approaches: 1. A parametric analysis of specific acoustic features logically connected to either vocal-fold activity or supralaryngeal filtering (i.e., Fo and resonance properties) combined with principle components analysis (PCA) dimension reduction and discriminant analysis call classification; 2. A holistic analysis of the global spectral structure of entire signals that combined a PCA-based eigenvector decomposition and neural network classification of the calls. We compare results of the two analysis strategies.

11:00

5aAB11. Decoding the information contained in the alarm calls of Gunnison prairie dogs. Con Slobodchikoff, William Briggs, and Patricia Dennis (Dept. Biol. Sci, Northern Arizona Univ., NAU Box 5640, Flagstaff, AZ 86011, Con.Slobodchikoff@nau.edu)

Gunnison prairie dogs have been shown to produce alarm calls that incorporate information about predators [Slobodchikoff *et al.*, Anim. Behav. **42**, 713–719 (1991)], such as the species of predator and also a description of the color and general size of the predator. The alarm calls contain a series of harmonics that encode this information. The calls have been analyzed with discriminant function analysis (DFA) and classification techniques such as self-organizing neural networks. These tools have been able to show that very specific information is encoded in the calls. However, exactly how this information is encoded into the signal has proven to be elusive. We show examples of the specific information that is encoded, and present a hypothetic model of how that information is encoded into the signals.

11:20

5aAB12. Processing acoustic features of animal vocalizations using classification procedures. Sean F. Hanser, Brenda McCowan (Dept. of Vet Med. Population Health and Reproduction, Univ. of California, 1 Shields Ave., Davis, CA 95616, sfhanser@ucdavis.edu), Laurance R. Doyle (SETI Inst., Mountain View, CA 94043), and Ann E. Bowles (Hubbs-SeaWorld Res. Inst., San Diego, CA 92109)

Remote methods for classifying age, sex, group membership, or individual identification of animals that live in visually obscured environments are extremely valuable tools for field biologists, but reliable identification of individual callers still presents important challenges. Acoustic features of animal vocalizations can be processed to extract caller identification using a variety of sophisticated classification techniques, but the exact classification process can be difficult to justify rigorously and challenging to repeat on novel data. A feature extraction and classification process that is clear, simple, and repeatable would be a major benefit to wildlife studies. Classification and regression trees (CART) generate intuitive and clear processes for handling multidimensional acoustic information. Examples of CART applied to Mexican spotted owl (*Strix occidentalus lucida*) and humpback whale (*Megaptera novaeangliae*) vocalizations will be provided. These CART results will be compared to other classification techniques, particularly neural networks. CART performance was comparable, but had the advantage that it yielded explicit classifiers used to categorize vocalizations, making it easy to integrate into acoustic surveying systems. This promises to be a valuable tool for conservation and management of these and other endangered species.

11:40

5aAB13. Hidden Markov models for the analysis of animal vocalizations. Patrick J. Clemins (525 N Pollard St., Apt. 419, Arlington, VA 22203, patrick@clemins.name) and Michael T. Johnson (Marquette Univ., Milwaukee, WI 53201)

Hidden Markov models (HMMs) are commonly used to model sequential data, including time series such as vocalizations. HMMs are uniquely suited to model time series because of their ability to implicitly align samples and to be linked together to create flexible recognition patterns for vocalizations with repeating patterns, such as bird and whale songs. HMMs require less human interaction and manual tuning for successful recognition and are inherently more noise resistant than template-based techniques. Due to their statistical basis, HMM-based recognition systems can incorporate additional statistical models. One such example is a language model, which can be designed to include *a priori* knowledge about the structure of the vocalizations, such as syllable repetition patterns. HMMs have become the most popular recognition model in speech processing, and this experience has been applied to a variety of vocalization analysis tasks including individual identification, song classification, call type recognition, and physiological state determination. Classification results from complete HMM-based systems for a variety of tasks and species will be discussed.

FRIDAY MORNING, 22 MAY 2009 PAVILION EAST, 8:15 TO 11:45 A.M.

Session 5aBB

Biomedical Ultrasound/Bioresponse to Vibration, Physical Acoustics and ASA Committee on Standards: Metrology and Calibration of High Intensity Focused Ultrasound

Peter J. Kaczkowski, Chair
Applied Physics Lab., Univ. of Washington, Seattle, WA 98105-6698

Chair's Introduction—8:15

Invited Papers

8:20

5aBB1. Improved impulse response for hydrophone measurements in therapeutic ultrasound fields. Michael S. Canney (Ctr. for Industrial and Medical Ultrasound, Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105), Vera A. Khokhlova, Oleg A. Sapozhnikov (Univ. of Washington, Seattle, WA), Yuri A. Pishchalnikov (Indiana Univ. School of Medicine, Indianapolis, IN), Adam D. Maxwell (Univ. of Michigan, Ann Arbor, MI), Michael R. Bailey, and Lawrence A. Crum (Univ. of Washington, Seattle, WA 98105)

The accurate measurement of pressure waveforms in high intensity focused ultrasound (HIFU) fields is complicated by the fact that many devices operate at output levels where shock waves can form in the focal region. In tissue ablation applications, the accurate measurement of the shock amplitude is important for predicting tissue heating since the absorption at the shock is proportional to the shock amplitude cubed. To accurately measure shocked pressure waveforms, not only must a hydrophone with a broad bandwidth ($>$100 MHz) be used, but the frequency response of the hydrophone must be known and used to correct the measured waveform. In this work, shocked pressure waveforms were measured using a fiber optic hydrophone and a frequency response for the hydrophone was determined by comparing measurements with numerical modeling using a KZK-type equation. The impulse response was separately determined by comparing a measured and an idealized shock pulse generated by an electromagnetic lithotripter. The frequency responses determined by the two methods were in good agreement. Calculations of heating using measured HIFU waveforms that had been deconvolved with the determined frequency response agreed well with measurements in tissue phantom. [Work supported by NIH DK43881, NSBRI SMST01601, NIH EB007643, and RFBR.]

8:40

5aBB2. Development of a high intensity focused ultrasound (HIFU) hydrophone system. Mark E. Schafer (Sonic Tech, Inc., 23 Brookline Ct., Lower Gwynedd, PA 19002, marks@sonictech.com) and James Gessert (Sonora Med. Sys., Longmont, CO 80503)

The growing use of high intensity focused Ultrasound (HIFU) has driven a need for reliable, reproducible measurements of HIFU acoustic fields. A reflective scatterer approach, incorporating several novel features for improved bandwidth, reliability, and reproducibility has been demonstrated [M. E. Schafer, J. Gessert, and W. Moore, Proc. IEEE Ultrasonics Symposium, 1739–1742 (2005)]. Several design improvements which have increase the signal-to-noise ratio of the system, and potentially reduced the cost of implementation, are now presented. For the scattering element, an artificial sapphire material is used to provide a more uniform radiating surface. The receiver is a segmented, truncated spherical structure with a 10 cm radius, made from 25 micron thick, biaxially stretched PVDF, with a Pt-Au electrode on the front surface. A specialized backing material provides the stiffness required to maintain structural stability, while at the same time providing both electrical shielding and ultrasonic absorption. This new receiver design has improved the noise performance by 8–12 dB; the new scattering sphere has reduced the scattering loss by another 14 dB, producing an effective sensitivity of −298 dB re 1 microVolt/Pa. The design trade-off still involves receiver sensitivity with effective spot size. However, the reduced cost and improved repeatability makes the overall design more robust for routine HIFU system measurements.

9:00

5aBB3. Characterization of high-intensity focused ultrasound systems by extrapolating from field measurements conducted in the quasi-linear regime. Samuel M. Howard (592 E. Weddell Dr., Sunnyvale, CA 94086, sh@ondacorp.com)

The purpose of this talk will be to discuss a method for characterizing HIFU fields where hydrophone measurements are made by reducing the electrical power input to the system until quasi-linear field propagation conditions are achieved, and until the pressure levels are safe for the hydrophone used. Radiation force measurements of total power are then used to scale up the results. This allows for reliable measurements which do not damage the hydrophone, and avoids complications from involving the many harmonics which can be generated in water which are usually not so strongly present in tissue. Advantages and disadvantages of the method will be discussed.

9:20

5aBB4. Temperature estimation and protocol assessment for monitoring high intensity focused ultrasound therapy with diagnostic ultrasound. Gavriel Speyer, Peter J. Kaczkowski, Andrew A. Brayman, and Lawrence A. Crum (Ctr. for Industrial and Medical Ultrasound, Appl. Phys. Lab., Univ. of Washington, Seattle, WA 98105-6698, gavriel@u.washington.edu)

Characterizing the performance of diagnostic ultrasound (DU) for monitoring high intensity focused ultrasound (HIFU) therapy is essential for identifying effective treatment protocols. Such protocols ensure accurate therapy monitoring in media with known thermal and perfusive properties. The protocols are specified by treatment duration, transducer motion, and the DU acquisition characteristics. The HIFU transducer is constrained to move in the plane perpendicular to its axis, with the DU positioned to capture the focal plane of the HIFU transducer. Differences in RF backscattering observed between two frames, one captured before and one after treatment, are known to result from a temperature distribution generated by the heat deposited during therapy. A functional expansion for the heating is used which provides minimum variance coefficient estimates for stationary backscattering by averaging the Fisher information matrix. We show through approximation, simulation, and experiment that these functions attain the Cramer-Rao bound independent of the particular heating applied or the RF backscattering encountered. Estimator accuracy is thus determined by the material properties, including the spatial correlation, and the protocol employed. Temperature estimates accurate to well within one degree Celsius are possible, and the estimation algorithm is implemented efficiently to enable near real-time monitoring. [Work supported by NIH Grant 5R01CA109557.]

9:40

5aBB5. Ultrasound-guided high intensity focused ultrasound therapy—Safety concerns from a clinical perspective. G. R. ter Haar (Inst. of Cancer Res. and Royal Marsden NHS Trust, Downs Rd., Sutton, Surrey SM2 5PT, UK, gail.terhaar@icr.ac.uk)

The use of high intensity focused ultrasound (HIFU) in surgical applications has continued to grow at a rapid pace. Nevertheless, safety concerns limit the adoption of ultrasound guidance due to the persistent lack of real-time monitoring and quantitative measures of clinical endpoints. Imaging and temperature estimation using magnetic resonance remains the preferred approach for guidance and monitoring in much of the Western world, while ultrasound imaging has seen wide use in China. Recent reviews of clinical outcomes have raised new regulatory concerns in China and are likely to increase scrutiny elsewhere. Still lacking are near real-time measures of *in situ* parameters such as acoustic power, heating rate, or temperature, from which clinical endpoint metrics may be obtained with acceptable accuracy. Furthermore, therapy planning remains a semiquantitative process, producing highly variable results, particularly in the absence of feedback. This presentation provides an update on the clinical impact of insufficient quantification of ultrasound-guided HIFU therapy.

10:00—10:30 Break

10:30

5aBB6. *Ex vivo* monitoring of high intensity focused ultrasound treatment. Xinliang Zheng and Shahram Vaezy (Dept. of Bioengineering, Box 355061, Univ. of Washington, 1705 NE Pacific St., Seattle, WA 98195, xlzheng@u.washington.edu)

High intensity focused ultrasound (HIFU) is a therapeutic modality that can produce coagulative necrosis of tissues noninvasively. The present study investigated the feasibility of monitoring lesion formation during HIFU treatment using ultrasound backscattered signal, specifically for treatments that do not result in hyperecho in ultrasound images (i.e., thermal lesion with no obvious boiling involved). *Ex vivo* chicken breast tissue was used and a sequence of two-dimensional radiofrequency (RF) signal was collected for each exposure as a function of time. For each frame in the RF sequence, one-dimensional cross correlation coefficient was calculated between every A-mode line of RF signal and the same line 5 seconds later. A series of experiments was performed with different HIFU treatment durations. The results showed that there was a decrease in the maximum coefficient value in the focal region during HIFU exposure, and a threshold value could be determined to be associated with the time that a thermal lesion was formed. Tissue dissection was performed to confirm the presence of a thermal lesion. This RF analysis technique has shown promise in detecting location and dimension of thermally-induced lesions, as well as being capable of real-time treatment monitoring to guarantee effective and efficient HIFU therapy.

10:45

5aBB7. Impact of temperature on bubbles excited by high intensity focused ultrasound. Wayne Kreider, Michael R. Bailey (Ctr. for Industrial and Medical Ultrasound, APL, Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, wkreider@u.washington.edu), Oleg A. Sapozhnikov (Moscow State Univ., Moscow 119992, Russia), and Lawrence A. Crum (Univ. of Washington, Seattle, WA 98105)

Bubble-enhanced heating is a current topic of interest associated with high intensity focused ultrasound (HIFU). For HIFU treatments designed to utilize acoustic radiation from bubbles as a heating mechanism, it has been reported that useful bubble activity diminishes at elevated temperatures. To better understand and quantify this behavior, a model has been implemented that couples the thermodynamic state of a strongly driven spherical bubble with thermal conditions in the surrounding liquid. This model has been validated over a range of temperature conditions against experimental data from the collapses and rebounds of millimeter-sized bubbles. With this model, the response of a micron-sized bubble was simulated under exposure to MHz/MPa HIFU excitation, while various surrounding liquid temperatures were considered. Characterizing the bubble response through the power spectral density of pressure radiated from the bubble, model calculations suggest that bubble collapses are significantly attenuated at temperatures above about 70°C. For instance, the acoustically radiated energy at 80°C is an order of magnitude less than that at 20°C. These results suggest that the efficacy of bubble-enhanced heating may be limited to temperatures below 70°C. Moreover, temperature will affect hydrophone measurements used to passively assess cavitation activity. [Work supported by NIH DK43881 and NSBRI SMST01601.]

11:00

5aBB8. Development of a tomographic cavitation sensor for quality assessment of clinical high intensity focused ultrasound systems. Stuart Faragher, Miklós Gyöngy (IBME, Univ. of Oxford, ORCB, Oxford OX3 7DQ, UK), Mark Hodnett, Adam Shaw (Natl. Physical Lab., Teddington TW11 0LW, UK), and Constantin-C. Coussios (Univ. of Oxford, ORCB, Oxford OX3 7DQ, UK)

High-intensity focused ultrasound (HIFU) fields are known to nucleate and excite inertial and noninertial cavitation in tissue and tissue-mimicking materials once a threshold negative acoustic pressure is reached. In the context of ablative HIFU treatment, inertial cavitation has been correlated with significantly enhanced rates of heating, while in histotripsy, cavitation is the very mechanism that causes tissue damage. Characterizing the extent of the cavitation region produced by clinical HIFU devices is therefore important to ensure safe, efficient, and effective treatment. A novel, multielement sensor is being developed to enable accurate axial and radial mapping of the cavitation region during HIFU exposure by passive detection and tomographic reconstruction of the broadband emissions arising from bubble collapse. Computational modeling has shown that the application of a cross-correlation algorithm to simulated received signals has the potential to localise individual sources of emissions with submillimeter accuracy. Initial experimental validation of models has been conducted using a prototype device developed in collaboration with the National Physical Laboratory. Future work will involve the refinement of the sensor design and reconstruction algorithm to improve spatiotemporal resolution, along with the development of a tissue mimicking material which matches the acoustic properties and cavitation threshold of real tissue.

11:15

5aBB9. A Schlieren system for optical visualization of ultrasonic fields. Peter J. Kaczkowski, Michael R. Bailey, Vera A. Khokhlova, and Oleg A. Sapozhnikov (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, peter@apl.washington.edu)

Ultrasonic field mapping is an essential component of transducer characterization and of beam forming verification. Such measurements are commonly performed by displacing a hydrophone over a range of points within the field; these procedures can be time-consuming. A calibrated hydrophone can provide accurate measurements of the field, subject to limitations of bandwidth and aperture of the device. A rapid qualitative 2D measurement of the spatial acoustic field can be obtained by optical means, in which the change in optical index due to the presence of acoustic pressure is imaged using a schlieren approach. This technique illuminates a transparent refracting acoustic medium using a plane collimated source and then focuses the transmitted light using a lens or mirror. In the absence of acoustic field, all of the light focuses to a small spot; acoustically induced refractive index perturbations cause some of the light to focus elsewhere. Obscuring the primary focal spot of unperturbed light with a mask permits imaging only the perturbations in the acoustic medium. We will describe a mirror-based schlieren system for imaging continuous as well as pulsed fields and with color corresponding qualitatively to the intensity of the field. [Work supported by NIH CA109556 and EB007643.]

11:30

5aBB10. Improved range-discriminating ultrasonic vibrometer. James Martin, Michael Gray, and Peter Rogers (Georgia Inst. of Technol., School of Mech. Eng., Atlanta, GA 30332-0405)

Improvements have been made to a previously reported continuous-wave ultrasonic vibrometer with range discrimination capabilities. In its current realization, the vibrometer incorporates a high-speed 16-bit arbitrary waveform generator as a signal source. The waveform generator shares a sample clock with the data acquisition system so that both the real and apparent spectral purity of each of the tones in a multitone carrier signal is preserved in the measurement. The new configuration provides increased control over the characteristics of the transmitted signal. It permits the exploitation of the full bandwidth capabilities of all of the hardware components of the system by removing a limit to the number of tones in the carrier. It also permits the relative phases of individual tones to be optimized in order to reduce the crest factor of the transmitted signal and better exploit the dynamic range of other system components. A further improvement in dynamic range has been achieved with an analog subtraction of the transmitter-receiver crosstalk, which is normally the largest received-signal component, prior to digitization. The improved vibrometer has been used to image shear wave fields in both tissue phantoms and inert tissue samples. [Work supported by ONR.]

Session 5aNS

Noise: Road Vehicle and Construction Noise—Measurement, Modeling, and Control

Kerrie G. Standlee, Chair
Daly-Standlee & Associates Inc., 4900 SW Griffith Dr., Suite 216, Beaverton, OR 97005

Contributed Papers

8:00

5aNS1. The City of Portland responds to urban gentrification through an investigation of noise sources within the boundaries of north Portland neighborhoods. Adam C. Jenkins and Julie A. Wiebusch (The Greenbusch Group, Inc., 1900 W. Nickerson St., Ste. 201, Seattle, WA 98119)

The North Portland area is a vibrant community, supporting residential populations, a wildlife reserve, and an active commerce. As Portland continues to attract new residents and residential areas expand in North Portland, the conflict between the residential desire for a peaceful environment and the commercial requirement to efficiently conduct business become more critical. The sustainability of the North Portland residential communites relies on planning decisions based on a well-defined understanding of the sound characteristics of the community. The City of Portland chose to study North Portland to better understand noise within its boundaries. The resulting noise mapping will serve as a tool for the City to use in future planning.

8:15

5aNS2. Noise mapping in Portland Oregon: The need to develop an approach to accurately depict the health impacts of short duration automotive racing noises emanating from a variety of motorized race events at the Portland International Racetrack facility. Paul van Orden (City of Portland Oregon, 1900 SW 4th Ave., Portland, OR 97201, pvanorden@ci.portland.or.us)

The City of Portland Oregon is in the final phase of completing its efforts to map one quadrant of the city in conjunction with the Greenbusch Group of Seattle Washington. The selection of this section of the city was identified for its notable concentration of noise sources ranging from the normal transportation related road, railway, and international airport sounds, to the unique and constantly varying tonal quality of automobile and motorcycle race groups at an international automotive raceway facility. The challenge to identify an appropriate method or standard to accurately depict the impact of these short term track races and drag races offers a unique opportunity to expand on the value of the noise mapping approach for long term urban planning efforts.

8:30

5aNS3. Prediction of noise from Portland International Raceway using environmental noise computer modeling techniques. Angus M. Deuchars (Arup Acoust., 560 Mission St., Ste. 700, San Francisco, CA 94105, angus.deuchars@arup.com)

An environmental noise computer model of Portland International Raceway has been constructed to evaluate noise mitigation at local noise sensitive receptors from making site wide changes to raceway infrastructure. There is little precedent of environmental noise computer modeling of raceways, and this paper presents the methodologies that were used to develop the computer model. Field measurements were made at the racetrack according to European Union Harmonoise methods to determine sound power levels of race vehicles; noise predictions were made using ISO 9613 pt 2 prediction model implemented using SOUNDPLAN software. Results from field measurements and predictions are presented to demonstrate accuracy of the computer model. Additionally, the innovative steps used to construct the computer model using sound plan are also presented.

8:45

5aNS4. A revised standard method for ground impedance measurement. Keith Attenborough and Shahram Taherzadeh (Dept. of Design, Development, Environment & Mater., The Open Univ., Milton Keynes MK7 6AA, UK, k.attenborough@open.ac.uk)

ANSI S1.18 (1998) for ground impedance measurement has been revised to combine the previously existing template method with direct deduction of impedance from data for the complex level difference between vertically separated microphones. It has been found that, despite the improved sensitivity at low frequencies that should be achievable through use of a longer range, the combined approach ceases to give reliable information for horizontal source-receiver separations of more than 1 m. The revised standard contains four worked examples: three grass-covered ground surfaces and a gravel road. The first example has been used to show that although use of consecutive measurements with a single microphone produces data that is usable with the template method, the phase information is not sufficiently robust to allow direct impedance deduction. In the three grassland examples, the widely used single parameter model is found to overpredict the real and imaginary parts of ground impedance at lower frequencies. The fourth example shows that the geometries prescribed in the standard are not appropriate for determining impedance spectra of relatively hard surfaces but are sufficient to establish that the surface is acoustically hard.

9:00

5aNS5. Sampling strategies for incorporating uncertainty and turbulent scattering into outdoor sound propagation calculations. Matthew S. Lewis, D. Keith Wilson (U.S. Engineer Res. and Development Ctr., 72 Lyme Rd., Hanover, NH 03755, D.Keith.Wilson@usace.army.mil), and Chris L. Pettit (U.S. Naval Acad., Annapolis, MD 21402)

The accuracy of mean sound-level estimates derived from different sampling methods is studied. The methods considered are Monte Carlo sampling (MCS), Latin Hypercube sampling (LHS), and Latinized Centroidal Voronoi Tessellation sampling (LCVTS). The goal is to determine which sampling method converges most rapidly to the actual mean sound level. The approach involves a model acoustic atmosphere, based on surface-layer similarity theory and a relaxation model for the ground, with sound fields calculated numerically with a parabolic equation solver. The range of consequences of epistemic uncertainty due to imperfect knowledge of the atmospheric and ground variables is examined through a simplified probabilistic model. Random (aleatory) uncertainty due to turbulent scattering also is considered. The samples are drawn randomly within the domain of uncertainty of the environmental variables. When only epistemic uncertainty is present owing to imprecise knowledge of the environmental variables, LCVTS is found to converge to an accurate estimate with the fewest number of samples, followed by LHS and then MCS. When random turbulent scattering is present, however, the sampling method has little effect on convergence.

9:15

5aNS6. Construction noise action area model. Larry J. Magnoni (Wash. St. Dept. of Trans., Env. Svs., Acoust., Air Quality, Energy Sec., 15700 Dayton Ave. N., PO Box 330310, Shoreline, WA 98133, magnonil@wsdot.wa.gov)

A model developed by the Washington State Department of Transportation to be used by biologists to determine the action area for highway construction projects is presented. The model conservatively estimates the distance at which construction noise would match ambient background sound levels. The model propagates the combined maximum sound level (Lmax) for project construction equipment spherically over the soft and hard site characteristics to a point where it would converge with the ambient hourly equivalent (Leq) sound level. The ambient Leq sound level can be input into the model from actual measurements, documented reference sources, or from a table based on population density [Federal Transit Authority (FTA) Noise Assessment Guidance (2006)]. The model then combines the ambient sound level with the traffic sound level based on the national mean emission curves. The input for traffic volume, vehicle type, and speed is propagated cylindrically from the source until the traffic source drops to the ambient level. A macro, that applies a general atmospheric and molecular absorption adjustment to the calculated distances, produces the action area circumference both graphically and numerically as it relates to each of the sound sources. [Work supported by the Federal Highway Administration (FHWA) (1978).]

9:30

5aNS7. Analysis of pile driver exhaust and impact noise. Edward Zechmann and Charles Hayden (Robert A. Taft Bldg., 4676 Columbia Pkwy., C-27, Cincinnati, OH 45226)

In July 2008, NIOSH accomplished a preliminary noise survey focused on gathering impulsive noise data from pile drivers. The purpose of the noise survey was to better understand the noise characteristics of pile drivers. NIOSH gathered time record data of H-beam piles being driven into hard rock. This data was used to characterize the frequency content of the major impulsive events (impact and exhaust cycles). Knowing the frequency content is necessary to apply existing or develop new noise controls, since many noise controls are frequency dependent. Gathering the frequency content of a pile driver's impulsive noise signal is typically difficult using off-the-shelf measurement and analysis equipment and software. Reliable time record data is necessary to confidently extract the frequency content from the signal. NIOSH has developed an Impulsive Noise Meter laptop program to properly gather and analyze these impulsive signals. By analyzing the third octave band peak levels of each impact and exhaust cycle of the pile driver operation, the frequency dependence was determined. Results of this analysis showed the frequency content varied as the pile was driven further into the ground. This implies that broad spectrum noise controls are necessary to control those noise emissions.

9:45

5aNS8. Are hybrid cars too quiet? Ryan L. Robart and Lawrence D. Rosenblum (Dept. of Psych., Univ. of California, Riverside, 900 University Ave., Riverside, CA 92521)

The increase in availability of alternative fuel vehicles has elicited concerns for pedestrians who might not hear the approach of these quieter cars. Three experiments tested the relative audibility of hybrid vehicles (in their electric mode) and internal combustion engine (ICE) cars. Binaural recordings were made of the cars approaching from either the right or left, at 5 mph. Subjects were asked to listen to these recordings over headphones and press one of two buttons indicating from which direction the car approached. Subjects' accuracies and reaction times were measured. The first experiment revealed that (sighted) subjects were able to determine the approach direction of the ICE cars substantially sooner than the hybrid cars. A second experiment added the natural background sounds of idling engines to the stimuli. The addition of background sound disproportionately hindered perception of the hybrid cars, so that they could not be localized until very close. A final experiment testing both sets of stimuli with blind subjects revealed the same pattern of results. Implications of these results for pedestrian safety will be discussed. [Work supported by a grant from the National Federation for the Blind.]

10:00—10:15 Break

10:15

5aNS9. Impulse noise reduction for hearing protectors. William Murphy (Natl. Inst. for Occupational Safety and Health, Div. Appllied Res. and Technol., Hearing Loss Prevention Team, 4676 Columbia Pkwy., MS C-27, Cincinnati, OH 45226-1998, wjm4@cdc.gov)

In 2009, the United States Environmental Protection Agency will propose a revision to the federal regulation for the labeling of hearing protection devices, 40 CFR 211 Subpart B. One of the new features of the proposed rule was the measurement of an impulse noise reduction rating for hearing protection devices. Measurement of impulsive sounds is challenging technically from an acoustics perspective. This paper will report on the performance of an acoustic shock tube used to generate impulses between 140 and 170 dB peak sound pressure level. The calibration methods for the microphones will be discussed and the measurements for a variety of hearing protectors will be presented. Typical earmuffs are capable of impulsive noise reduction ratings of between 20 and 35 dB. Earplugs provide similar range of performance. Combinations of earmuff and earplug have yielded impulse peak reductions of more than 50 dB. The reduction of the impulse peak level should provide a means to predict exposure at the ear when a hearing protector is worn in an impulsive noise environment.

10:30

5aNS10. Noise barriers based on recycled materials. Jose Sanchez-Dehesa, Victor Garcia-Chocano, Daniel Torrent, Francisco Cervera, and Suitberto Cabrera (Wave Phenomena Group, Polytechnic Univ. of Valencia, Camino de vera s.n., ES-46022 Valencia, Spain, jsdehesa@upvnet.upv.es)

Two-dimensional sonic crystals consisting of arrays of cylinders fabricated with recycled materials (rubber crumb) are proposed to reduce efficiently the noise. The attenuation by these barriers is produced by a combination of sound absorption by the rubber crumb and Bragg reflection by the ordered cylinders. Experiments performed in an anechoic chamber support the predictions by the multiple scattering theory. An optimization method is also reported to develop sound barriers for traffic noise. [Work supported by Spanish MICIIN.]

10:45

5aNS11. Quenching of bandgaps by flow noise. Jose Sanchez-Dehesa (Wave Phenomena Group, Polythecnic Univ. of Valencia, Camino de vera s.n., Spain, ES-46022, jsdehesa@upvnet.upv.es), Tamer Elnady, Adel Elsabbagh, Wael Akl, Osama Mohamady (Ain Shams Univ., Cairo, Egypt), Victor Garcia-Chocano, Daniel Torrent, and Francisco Cervera (Polythecnic Univ. of Valencia, ES-46022, Spain)

We report an experimental study of acoustic effects produced by wind impinging on noise barriers based on two-dimensional sonic crystals with square symmetry. We found that the attenuation strength of sonic-crystal-bandgaps decreases for increasing values of low speed. A quenching of the acoustic bandgap appears at a certain speed value that depends of the barrier filling ratio. For increasing values of low speed, the data indicate that the barrier becomes in a sound source because of its interaction with the wind. We conclude that flow noise has paramount importance in designing acoustic barriers based on sonic crystals. [Work supported by Spanish AECI.]

11:00

5aNS12. Leakage identification for a vehicle firewall sound transmission by beamforming technique. Yuri Ribeiro (GM do Brasil, Indaiatuba, Sao Paulo, Brazil), William Fonseca, and Gerges Samir (Fed. Univ. of Santa Catarina, Florianopolis, SC, Brazil)

The acoustic phased array is a powerful tool for identification and quantification of noise sources on complex systems. Acoustic sources generate waves which propagate through space to the N microphones of the array. The acoustic pressures are sampled and converted to time series data and processed using either time domain or frequency domain delayed and averaged. The output of signal processing is a colored image with relative sound pressure levels distribution. In this paper application of beamforming technique is used to identify leakage areas in a vehicle firewall. Two acoustic rooms are used and the firewall was installed in the apertures inbetween with careful control of noise flank paths. Source room was excited with white noise and a phased array microphone was used to measure the sound field in the anechoic receiving room. The firewall was evaluated both with all holes sealed and with the regular pass-through components installed. Two different acoustic insulators were also tested on the firewall. The results show clearly the areas of leakage with relative noise levels at each test configuration.

FRIDAY MORNING, 22 MAY 2009 BROADWAY III/IV, 8:30 TO 10:00 A.M.

Session 5aPA

Physical Acoustics: General Physical Acoustics II

Kai Ming Li, Chair
School of Mechanical Engineering, Ray W. Herrick Labs., Purdue Univ., West Lafayette, IN 47906

Contributed Papers

8:30

5aPA1. Using sound radiation to characterize binary collisions of polypropylene balls. J. Riner and A. Petculescu (Dept. of Phys., Univ. of Louisiana, P.O. Box 44210, Lafayette, LA 70504)

An acoustic method to check the validity of Hertz's law and characterize the source characteristics of binary collisions is proposed. The technique uses a goniometer equipped with a microphone to detect the sound produced by collisions between two solid polypropylene balls. The collisions are the result of a projectile ball falling from rest and striking a rigidly mounted target ball. The acoustic field in both the horizontal and the vertical plane is sampled and the maximum and minimum pressures, as well as frequency content, are studied. The power spectrum has a dominant peak at approximately 10 kHz. Radiation in the horizontal plane is found to be mostly symmetric about the collision point while there is an observed asymmetry in the vertical plane, which can be used to infer the characteristics of the source of audible sound. The acoustic signals are likely generated by the relative accelerations of the two balls and not by the normal vibrational modes, which were measured to start at about 73 kHz. [Work funded by the Louisiana Board of Regents.]

8:45

5aPA2. Pulse propagation in a hyperlattice. Joseph Dickey (Adv. Technol. Lab., The Johns Hopkins Univ., 810 Wyman Park Dr., Baltimore, MD 21211)

The classical dynamics and pulse propagation are presented for a series of latticelike structures whose spatial dimensionality ranges from one to four: four representing a hyperlattice. The lattices are connected 1-D wave bearing systems of varying lengths and can illuminate some aspects of higher dimension structures. Short pulses are launched at an arbitrary point, reverberate throughout the entire structure, and detected at another point. Some aspects of increasing dimensionality are illustrated with particular emphasis on the transition from three to four spatial dimensions. In a hypothetical 4-D world where only three are observable, the classical conservation laws and causality do not hold. The lack of causality is illustrated at each step in dimensionality by showing the "unexpected" pulse returns from the next higher dimension.

9:00

5aPA3. Scattering of compressional waves by a cavity in an elastic solid: Geometric interpretation and beam illumination. Likun Zhang and Philip L. Marston (Phys. and Astron. Dept., Washington State Univ., Pullman, WA 99164-2814, zhanglikun@wsu.edu)

Aspects of the scattering of short-wavelength compressional waves by an empty spherical cavity in an elastic solid may be predicted geometrically from the elastic wave reflection coefficient for a plane surface and the curvature of the reflecting surface. When the outgoing wave is a shear wave, it is necessary to include the modified ray-tube parameters associated with mode conversion. Related geometrical considerations are also helpful for interpreting the scattering of a compressional wave Bessel beam by an empty spherical cavity centered on the beam in an elastic solid. The exact solution in that case follows from a generalization of the scattering analysis for acoustic Bessel beams [P. L. Marston, J. Acoust. Soc. Am. **121**, 753–758 (2007)]. A modified analysis gives the directional dependence of the shear waves resulting from mode conversion for a cavity on the axis of a compressional wave Bessel beam. For both plane wave and Bessel beam illumination, the scattering pattern can depend strongly on the value of the Poisson ratio of the solid.

9:15

5aPA4. Measurement of acoustic wave frequency by Bragg light diffraction. R. Farkhad Akhmedzhanov (Dept. of Phys., Navoi State Mining Inst., 27a Yuzhnaya St., Navoi 210100, Uzbekistan, farkhad2@yahoo.com)

The new technology is offered for measurement of acoustic wave frequency. The method is based on using the Bragg light diffraction on the hypersonic transversal acoustic wave in a gyrotropic crystal. As is well known, the intensity of diffracted light in this case is strongly dependent from the quantity of specific rotation of polarization vector. As a result, using the standard calibration of light intensity it is possible to measure the changes of acoustic wave frequency. Measurements of the diffracted light intensity have been carried out in several points along the direction of the acoustic wave propagation. The applied sample of LiNbO3 was oriented along the crystallographic axis of the third order with the accuracy of 10′. The plane-polarized transverse acoustic waves were excited in the frequency range from 900 MHz to 1.2 GHz. The results obtained at the average frequency 1.0 GHz were shown, that the intensity of diffracted light intensity is sensitive parameter to the change of the transverse acoustic wave frequency. The dependence of the diffracted light intensity from the quantity of specific rotation frequency was used for determination of the acoustic wave frequency by the appropriate model equation accurate within 0.1%.

9:30

5aPA5. Acoustic cavities with radial sonic crystals. Daniel Torrent and José Sánchez-Dehesa (Wave Phenomena Group, Polytechnic Univ. of Valencia, Camino de Vera s.n. ES-46022, datorma1@upvnet.upv.es)

Radial sonic crystals in two and three dimensions are introduced. These materials have the property of leaving the acoustic wave equation invariant under radial displacements, and then they present a "radial band structure" similar to that of one dimensional sonic crystals. Finite shells of radial sonic crystals can be used as resonant cavities. The radiation pattern of these cavities will be reported. For example, it will be shown that a cavity can be used as a dipolar source by placing a monopole inside the cavity. Finally, physical realization of radial sonic crystals is discussed in two and three dimensions [Work supported by Spanish MICIIN and Consolider Program.]

9:45

5aPA6. Acoustic cloaking in two and three dimensions. Daniel Torrent and José Sánchez-Dehesa (Wave Phenomena Group, Polytechnic Univ. of Valencia, Camino de Vera s.n. ES-46022, datorma1@upvnet.upv.es)

The cloaking theory is analyzed in two and three dimensions. It is shown that cloaks require materials with some special properties not known in nature, mainly, they need to be fluid-like materials with anisotropic, inhomogeneous, and locally divergent acoustic properties. The anisotropy problem is solved with the help of the so-called "metamaterials", the inhomogeneous behavior is implemented with stratified scatterers and the divergence of the parameters is avoided with the concept of "imperfect cloaks", which transforms the scattering cross section of an object of radius R in that of an object of radius $R' \ll R$. [Work supported by the Spanish MICIIN and the Consolider Program.]

FRIDAY MORNING, 22 MAY 2009 PAVILION WEST, 8:30 TO 11:05 A.M.

Session 5aUW

Underwater Acoustics: Sediment Acoustics

Kevin L. Williams, Chair
Applied Physics Lab., Univ. of Washington, Seattle, WA 98105

Chair's Introduction—8:30

Contributed Papers

8:35

5aUW1. The effects of scattering from heterogeneities in porosity during sound propagation through sand sediments. Brian T. Hefner, Darrell R. Jackson (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105-6698), and Joseph Calantoni (Naval Res. Lab., Stennis Space Ctr., MS 39529)

Sand sediments are inherently heterogeneous due to the random packing of the grains. For sound propagation through fluid-saturated sediments, these heterogeneities may lead to scattering from the coherent fast compressional wave into incoherent slow compressional waves or shear waves. This loss of energy from the fast compressional wave may account for the increase in high-frequency attenuation above that predicted by Biot theory. In a previous talk, we presented preliminary results of applying perturbation theory to Biot theory in order to model scattering from heterogeneities in the porosity [Hefner *et al.*, J. Acoust. Soc. Am. **120**, 3098 (2006)]. This theory has since been refined to properly account for scattering into both the slow compressional wave and the shear wave. In order to apply this theory to a given sand sediment, knowledge of the covariance function for the spatial variations in the porosity is required. Results of the theory will be presented for several different analytic covariance functions, as well as for covariance functions measured in simulated and real unconsolidated granular materials.

8:50

5aUW2. Sand acoustics: The effective density fluid model, Pierce/Carey expressions, and inferences for porous media modeling. Kevin Williams (Appl. Phys. Lab., College of Ocean and Fishery Sci., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, williams@apl.washington.edu)

Recently, Pierce and Carey [JASA-EL **124**, EL308–EL312 (2008)], presented a low-frequency analysis of sound propagation in sand/silty sediments. Here, equivalent expressions are presented using a low frequency expansion of an unconsolidated version of Biot porous medium theory (i.e., the effective density fluid model (EDFM)). The resulting expression for attenuation allows identfication of the nondimensional parameter in the Pierce /Carey result in terms of physical parameters. One of the important aspects of the Pierce/Carey derivation is that they show how to account for the inertial effects due to the relative grain/fluid density. The agreement between the Pierce/Carrey and EDFM low-frequency attenuation expressions motivates further frequency and relative grain/fluid density analyses of attenuation and sound speed. The general inference of these analyses is that any model that ignores inertial effects due to differences in grain and fluid density is missing a key piece of physics that makes it incomplete. Wood's equation is one such model and since the Buckingham model uses Wood's equation, it is another example. The point being that the use of the mass density to handle inertia in a porous medium is a low-frequency approximation. [Work supported by the Office of Naval Research.]

9:05

5aUW3. Acoustic measurement of fines. Wayne Carpenter (Natl. Ctr. for Physical Acoust., Univ. of Mississippi, 1 Coliseum Dr., University, MS 38677, wocarpen@olemiss.edu), Daniel Wren, Roger Kuhnle (USDA-ARS-NSL, Oxford, MS 38655), and James Chambers (Univ. of Mississippi, University, MS 38677)

The measurement of sediment particles <100 microns in diameter suspended in water has received little attention; however, particles of this size can account for a large fraction of the material transported in streams and rivers. In order to advance the current state of knowledge, the use of acoustic techniques as a surrogate measurement for the concentration of fine sediment particles in water is investigated. Both backscatter and attenuation will be evaluated as potential measurement techniques using a laboratory tank. Based on experience with the use of 1–5 MHz frequencies for backscatter measurements of particles in the 100–1000 micron size range, initial work will focus on the use of a frequency of approximately 20 MHz. The attenuation and backscatter due to a range of concentrations of bentonite and kaolinite will be reported.

9:20

5aUW4. High-frequency acoustic properties of water-saturated sediments: Laboratory study. Jean-Pierre Sessarego, Rgine Guillermin (CNRS/LMA, 31 Chemin Joseph Aiguier, 13402 Marseille, France), and Anatoly N Ivakin (Univ. of Washington, Seattle, WA 98105)

This study was performed in controlled laboratory conditions using several broadband transducers to cover a wide frequency range from 200 kHz to 3MHz. Various types of sediments were used: natural medium and coarse sand, and glass beads with corresponding mean sizes. Sound speed and attenuation were measured and compared with predictions of Biot theory. The theory failed to predict both high attenuation and negative dispersion of sound speed observed at very high frequencies (above 500 kHz for medium sands), which can be assumed an effect of strong grain scattering. All the measurements were performed at different times to ensure the repeatability of the results. A comparison of results obtained for natural sands with those for artificial sediment (glass beads) of the same mean size, allowed observing the influence of the grain shape on the reflected and backscattered signals. Also, the influence of the transducer directivity diagram on the sediment reflectivity was observed. This effect is discussed and shown to be essential in the case of strong incoherent scattering observed for coarse sediments. Finally, the time-frequency contents of the reflected signal were analyzed. It was found to be very sensitive to the granular structure of the sediment. [Work supported by CNRS and ONR.]

9:35

5aUW5. Direct numerical simulation of the acoustic virtual mass of granular media. Joseph Calantoni (Marine Geosciences Div. Naval Res. Lab., Stennis Space Ctr., MS 39529, joe.calantoni@nrlssc.navy.mil) and B. Todd Hefner (Univ. of Washington, Seattle, WA 98105-6698)

The theory of acoustic virtual mass in granular media hypothesizes that during sound propagation, energy is transferred out of the direction of propagation and into rotational and transverse degrees of freedom that act as an additional virtual mass, thus decreasing the sound speed. We use a discrete element model that explicitly simulates the motions and interactions of every particle in a finite volume to examine the theory of acoustic virtual mass. Simulations are fully three-dimensional where the physical properties, such as size, density, and shape (typically spherical), of every grain may be uniquely specified. Normal and tangential forces at grain-grain contact points are modeled with springs and friction, respectively. Depending on the material of interest (e.g., quartz grains), several normal contact force laws are available including linear elastic, linear elastoplastic, and Hertzian. Likewise, the tangential contact force is typically modeled with a stick-slip behavior using a linear spring and friction, but other variations are available. Sound speed and attenuation are calculated by propagation of pulses through the simulated materials and these results are compared to the predictions of theory with and without the virtual mass term.

9:50

5aUW6. Synthesizing the shape of sand grains. David R. Barclay and Michael J. Buckingham (Scripps Inst. of Oceanogr., Marine Phys. Lab., Univ. of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0238, dbarclay@mpl.ucsd.edu)

Digitized outlines of sand grains from a dozen locations have been acquired using an optical microscope. A Fourier decomposition of the outline is calculated providing a spectral description of the grain's shape. By averaging over several hundred grains, the normalized power spectrum of each sand sample is returned. The desert sands, beach sands, and marine sediments measured all exhibit the same inverse-power-law dependence on the harmonic number, n, varying as $n^{-10/3}$ for $2 \leqslant n \leqslant 20$. This "universal" spectrum provides the basis of a numerical technique for synthesizing the irregular outline of a sand grain: the outline is represented as a random pulse train in which identically shaped microasperities, with normally distributed amplitudes, are randomly superimposed on the perimeter of a circle. Carson's theorem links the power spectrum of an individual microasperity to that of the real grains and constrains the synthetic outlines to have the identical statistical properties as the outlines of the measured samples. Visually, it is difficult to distinguish between the synthesized and real outlines. This numerical technique for synthesizing irregular outlines of grains has potential for investigating the random-packing of realistically rough particles through computer simulation. [Work supported by the Office of Naval Research.]

10:05—10:20 Break

10:20

5aUW7. Uncertainty estimation of sound attenuation in marine sediments at low frequencies. Yong-Min Jiang and N. Ross Chapman (School of Earth and Ocean Sci. , Univ. of Victoria, P.O. Box 3055 Victoria, BC, V8W 3P6 Canada, minj@uvic.ca)

Marine sediment attenuation at low frequencies (under 5 kHz) is generally difficult to be directly measured by *in situ* probes embedded in the sediment, partly due to the very short propagation distances. An alternate experimental technique is to use single bottom bounce signals received by a vertical line array. The frequency dependence of the sediment attenuation is first obtained by comparing the amplitude differences of the sea floor reflection and the sub bottom layer reflection at different frequencies. The absolute attenuation is then obtained by using the previously estimated sound speed and layer thickness. Inherently there is uncertainty introduced in each stage of the attenuation estimation procedure. To evaluate the uncertainty of the attenuation estimate, the standard deviation of the signal fluctuation is mapped to the intermediate result first, and then Bayesian inversion results of the sound speed and the layer thickness are included in the final attenuation estimates. This uncertainty analysis is demonstrated by the estimation of the sediment attenuation from the low frequency chirp data collected in a variable water column environment in the Shallow Water 06 experiment. [Work supported by ONR Ocean Acoustics.]

10:35

5aUW8. On the use of acoustic particle motion in geoacoustic inversion. Steven E. Crocker (Naval Undersea Warfare Ctr., 1176 Howell St. Newport, RI 02841), James H. Miller (Univ. of Rhode Island, Narragansett, RI 02882), Paul C. Hines, and John C. Osler (Defence R&D Canada Atlantic, Dartmouth, NS B2Y 3Z7, Canada)

Geoacoustic inversion estimates sediment properties based on one or more parameters of an observed acoustic field via inverse mathematical methods. The observed acoustic parameter is usually derived from the acoustic pressure measured at one or more locations. Recent advances in acoustic sensor technology have enabled the simultaneous measurement of the acoustic pressure and particle motion in three dimensions. The additional information provided by such acoustic vector sensors can be used to improve the performance of existing and novel geoacoustic inversion techniques. Current research seeks to use the additional information that is provided by the acoustic vector sensor to pose new inverse problems for the estimation of seabed sediment properties. In particular, data collected during the Sediment Acoustics Experiment 2004 (SAX04) included acoustic pressure and particle acceleration from a small number of acoustic vector sensors arranged in a vertical line, spanning the water-sediment interface. A variety of waveforms were transmitted into the seabed to measure the direct, reflected, and transmitted waves. Experiment details, forward modeling, inversion methods, and results are discussed. [Work supported by ONR.]

10:50

5aUW9. Study of interface wave generation and shear wave velocity estimation. Hefeng Dong (Dept. of Elect. and Telecom., Norwegian Univ. of Sci. and Technol., NTNU, No-7491 Trondheim, Norway and School of Earth and Ocean Sci., Univ. of Victoria, BC, V8W 3P6 Canada) and Ross Chapman (Univ. of Victoria, BC, V8W 3P6 Canada)

Estimation of the shear wave velocity profile versus depth and shear wave attenuation in the upper sediment layers has been an important research topic in underwater acoustics. The shear wave velocity profile is insensitive to hydrophone data measured in water column, while dispersion of the interface wave propagating along the water and sea bottom boundary (the Scholte wave) is closely related to shear wave velocity variation with depth in the upper sediment layers. However, due to the exponential decay of the amplitude of the interface waves, there may be no interface waves generated and recorded in a conventional underwater experiment configuration where the sources and receivers (vertical and/or horizontal hydrophone array) are located in the water column with distance (measured by wavelength of the interface wave) away from water bottom interface. In this paper the conditions in which interface waves can be generated, recorded, and visualized are studied by numerical experiments in the underwater environment. The conditions include source strength, frequency band, source–receiver configuration, and signal-to-noise ratio, etc. Examples are given for estimating of shear wave velocity profile with depth by inverting dispersion curves of recorded interface waves in real data. [Work supported by NFR under Contract No. 186923/I30.]