of the computing power of GPU in the next years are evaluated together with future possibilities that GPU architectures might bring to FDTD applied to room acoustics.

11:20

5aUW8. Efficient implementation of power-law attenuation of elastic waves in time-domain numerical simulations. David C. Calvo (Acoust. Div., Naval Res. Lab., 4555 Overlook Ave., SW, Washington, DC, david.calvo@nrl.navy.mil) and Gaetano Canepa (Ctr. for Maritime Res. and Eng., La Spezia, Italy)

Numerical simulation of wave propagation in the time domain is easily parallelizable on high performance computing systems due to the spatially local nature of the governing equations. The disadvantage of working in the time domain arises when lossy media must be modeled which generally gives rise to convolution-type loss terms in the governing time-domain equations. Computation of these convolutions usually requires the storage of several solution fields at thousands of previous time steps. This requirement can be memory prohibitive in three-dimensions. In this talk we present a recursive convolution approach to computing lossy (power-law) elastic wave propagation that is an extension of the one-way, one-dimensional acoustic wave equation work done by Liebler [Liebler *et al.*, J. Acoust. Soc. Am. **116** (2004)] in order to handle multiple dimensions and shear waves. Convolutions are computed recursively by first using a nonlinear least-squares technique to fit the kernel of the convolution with a series of decaying exponentials. We demonstrate how graphical processing units (GPUs) can be used to obtain speed-up factors as high as 35 on a test computation of time-domain scattering from a highly resonant but lossy elastic cylinder. [Work sponsored by the Office of Naval Research.]

11:40

5aUW9. The use of graphical processing unit processing in rough surface scattering. Ahmad T. Abawi and Paul Hursky (HLS Res., 3366 North Torrey Pines Court, La Jolla, CA 92037, abawi@hlsresearch.com)

The use of graphical processing units (GPU's) in scientific computation has drawn significant interest in recent years. In this paper we use GPU processing to evaluate the performance of a number of approximate techniques in computing scattering from two-dimensional rough surfaces by comparing their results with those obtained using the boundary element technique, which produces a numerically exact solution of the problem. To compute scattering from a two-dimensional surface, we use a technique that we developed for computing scattering from compact objects, which uses an analytical expression for scattering from a single, flat triangle. In this technique the surface is meshed using triangular patches and the scattering is computed as a coherent sum of scattering from individual triangles. This technique not only provides accurate evaluation of the surface integrals that appear in scattering theory, but it also lends itself easily to the benefits of GPU processing. We apply this technique to the Kirchhoff approximation, the small slope approximation and to a rather less familiar technique based on the work of Dashen *et al*. [J. Math. Phys.**32**, 986–996 (1991)].

12:00

5aUW10. Reverberation modeling on graphics processing units. Paul Hursky and Ahmad T. Abawi (HLS Res. Inc., 3366 North Torrey Pines Court, Ste. 310, La Jolla, CA 92037, paul.hursky@hlsresearch.com)

We will discuss modeling reverberation on GPUs. An accompanying talk will discuss using GPUs to model scattering from rough surfaces. Here we discuss using GPUs to model the two sets of propagation paths, one set from the source to scatterer, the other set from the scatterer to the receiver, and to combine these two sets via a scattering operation and assemble the reverberation waveform at the receiver. We will discuss how we have adapted various aspects of our modeling to a GPU platform. GPUs provide several differentiated memory architectures that an application can exploit. For example, the texture memory provides hardware-assisted interpolation—as a result, we can load a 3D environment into texture memory, sparsely sampled, and then reconstruct interpolated slices as needed the modeling task. GPU architectures have been evolving for many years to meet the demands of computer gaming and rendering, applications most ambitiously served by ray tracing (of light). As a result, NVIDIA provides a ray tracing framework called OptiX, sufficiently general-purpose, that it can be linked with externally provided functions to specialize the mathematics implemented during the ray trace process. We will describe our work on adapting OptiX to underwater acoustic ray tracing.

FRIDAY AFTERNOON, 7 JUNE 2013 — 514ABC, 1:00 P.M. TO 2:40 P.M.

Session 5pPP

Psychological and Physiological Acoustics: Recent Trends in Psychoacoustics II

Hugo Fastl, Cochair
AG Technische Akustik, TU München, Arcisstr.21, München 80333, Germany

Sonoko Kuwano, Cochair
Osaka Univ., 2-24-1-1107 Shinsenri-Nishimachi, Toyonaka, Osaka 560-0083, Japan

Invited Papers

1:00

5pPP1. What can we learn from simulated acoustic environments? Bernhard U. Seeber (Audio Information Process., Technische Universität München, Arcisstrasse 21, Munich 80333, Germany, seeber@tum.de)

Psychoacoustic research has often used headphones to reproduce sound stimuli. Recently, the spatial dimension has regained attention in basic research and the talk will make a case for the importance of binaural hearing when assessing sound quality. Technological advances made it possible to accurately reproduce real and artificial sound stimuli with high spatial fidelity for their assessment. The Simulated Open Field Environment (SOFE) is a laboratory setup to reproduce sounds from multiple loudspeakers in an anechoic chamber. The free-field presentation allows participants to interact with sound stimuli in a natural way using head turns and movements - important when working with participants inexperienced with laboratory procedures. In connection with room simulation software the SOFE can also create acoustic scenes with multiple sources and sound reflections—thereby increasing the realism. I will give an overview of recent findings gained with the SOFE and their relation to evaluating sound quality.

1:20

5pPP2. A cognitive approach for binaural models using a top-down feedback structure. Jonas Braasch, Anthony Parks (Ctr. for Cognit., Commun., and Culture/Architectural Acoust., Rensselaer Polytechnic Inst., Greene Bldg., 110 8th St., Troy, NY 12180, braasj@rpi.edu), and Jens Blauert (Inst. of Commun. Acoust., Ruhr-Univ. Bochum, Bochum, Germany)

Current models to explain binaural hearing generally focus on bottom-up processes of the auditory periphery and subcortical brain functions to simulate sound localization and other binaural tasks. While these models have been very successful in explaining a number of psychoacoustic phenomena, their architecture is not suitable to explain experiments that involve cognition. The project presented here seeks to close the gap between functional binaural models and research in applied robotics. A software architecture that was originally designed to simulate the process of music improvisation using a combination of Computational Auditory Scene Analysis, machine learning and logic-based reasoning, the Creative Artificially Intuitive and Reasoning Agent (CAIRA) was extended to simulate a number of basic binaural phenomena including sound localization of multiple-sources, resolving front/back confusions through strategic head movements, and adapting inhibitory parameters to the presented signals to evoke localization dominance. [Work supported by the National Science Foundation, No. 1002851.]

1:40

5pPP3. Continuous features of emotion in classical, popular, and game music. Masashi Yamada (Dept. of Media Informatics, Kanazawa Inst. of Technol., 3-1 Yatsukaho, Hakusan, Ishikawa 924-0838, Japan, m-yamada@neptune.kanazawa-it.ac.jp)

In the present study, musical emotion was measured continuously for classical, popular and game music. Eight pieces for each genre were used as stimuli. The following computer system was prepared: The screen showed a cursor on a two-dimensional plane spanned by valence (pleasant-unpleasant) and arousal axes. The position of the cursor was manipulated by a mouse and recorded every 0.5 s. In one session, the system continuously recorded the emotional responses of 20 listeners while listening to each piece. In the other session, the listeners listened to each piece without manipulating the mouse, and then pointed out the overall emotional feature of the piece on the two-dimensional plane. The results showed that the valence did not vary largely for any genre. The arousal varied largely for classical music, but not for game music. For popular music, it varied in between classical and game music. For all genres, the overall emotional values of valence and arousal showed almost equal to the maximum or minimum values in the continuous variation, respectively. This implies that the overall emotional features of a musical piece are almost entirely determined by the part which shows the highest degree of emotion in the piece.

2:00

5pPP4. Perceptual outcomes by rapid alternation of the resonant scaling and its relation to the fundamental frequency. Minoru Tsuzaki (Faculty of Music, Kyoto City Univ. of Arts, 13-6 Kutsukake-cho, Oe, Nishikyo-ku, Kyoto 610-1197, Japan, minoru.tsuzaki@kcua.ac.jp), Chihiro Takeshima (J. F. Oberlin Univ., Machida, Japan), Toshie Matsui (Dept. of Otorhinolaryngol., Nara Med. Univ., Kashihara, Japan), and Toshio Irino (Faculty of System Eng., Wakayama Univ., Wakayama, Japan)

Timbre provided by the resonant characteristics of the vibrating body can be represented as spectral envelope patterns and can contribute as one of the important cues for sound source identification. However, its concept is not strictly established while that of loudness, and of pitch are well known. Recently, the fact that the spectral pattern can be decomposed into two factors, i.e., the shape and size of the resonant body, has been reconsidered. Several psychophysical findings have successfully suggested that a "bottom-up" perceptual mechanism of the decomposition might be implemented. Manipulating the scaling factor of resonance can change the perceptual size of the sound source. By concatenating synthesized vowel segments whose resonant scale (RS) alternates between two values in an "ABA-ABA-" fashion, one can generate series of test stimuli for stream segregation with the galloping rhythm paradigm. The experimental results revealed that the RS factor could provide a reliable cue for streaming. As an extreme variation of this RS alternation, scale alternating wavelet sequences (SAWSs) have been proposed. In the SAWS, the RS alternates at every regular time grid. When the difference between the two RS factors exceeded a certain limit, perceived pitch shifted downwards by an octave.

Contributed Paper

2:20

5pPP5. Neuroacoustics: Study on the perception of stereo reverberant sound field at cortical level. Alejandro Bidondo (Ciencia y Tecnología, Universidad Nacional de Tres de Febrero, Av. De Los Constituyentes 1426, Villa Maipú. San Martín. Buenos Aires 1650, Argentina, abidondo@untref.edu.ar)

On the basis of the Ando's brain hemispheric specialization auditory model, spatial information is processed in the right hemisphere. When hearing a complex sound stimuli, like a monaural sound source reproduced in a reverberant sound field, several independent acoustic cues are processed in both hemispheres simultaneously. To study the brain specialization perceiving these types of sounds, it was developed the Auditory Evoked Potentials analysis for 2000 ms after the first 80 ms from the sound onset, even though the first 300 ms is normally analyzed, and Cortical Activity descriptors, which were applied to mismatch negativity electro-physiological signals taken from left and right hemispheres. It was possible to measure the specialization of hemispheres by using two different monaural and anechoic sound sources, one with a minimum effective duration of its autocorrelation function (tau e) as low as 0.2 ms and another with minimum tau e of 190 ms, both embedded into the same reverberant sound field and reproduced through headphones. This study opens the possibility to measure the perception of listener envelopment to further develop a subjective descriptor.

Session 5pSC

Speech Communication: Flow, Structure, and Acoustic Interactions During Voice Production II

Scott L. Thomson, Chair
Mech. Eng., Brigham Young Univ., 435 CTB, Provo, UT 84602

Contributed Papers

1:00

5pSC1. Quantification of the false vocal-folds effects on the intra-glottal pressures using large eddy simulation. Mihai Mihaescu (KTH Mekanik, Linné FLOW Ctr., Royal Inst. of Technol. (KTH), Osquars Backe 18, Stockholm 10044, Sweden, mihai@mech.kth.se), Sid M. Khosla (Otolaryngol. -Head and Neck Surgery, Univ. of Cincinnati-Medical Ctr., Cincinnati, OH), and Ephraim J. Gutmark (Aerosp. Systems, Univ. of Cincinnati, Cincinnati, OH)

During the closing phase of the phonation cycle the true vocal-folds (TVF) have a convergent-divergent shape. The negative pressures generated by the flow through the glottal passage are producing closing forces acting on the TVFs towards the center of the larynx. Intra-glottal pressures can affect both vocal-fold vibration and voice production, since they can accelerate the closing phase. This has a positive impact on the voice quality. Large Eddy Simulation approach is used to investigate the intra-glottal forces generated solely by the flow during the closing phase. The influence of the gap between the false vocal-folds (FVFs) and the location of FVFs with respect to the TVFs are analyzed. Based on anatomical measurements, four different gaps between the FVFs and two different distances between the true and false vocal-folds are investigated for the same trans-laryngeal pressure. The TVFs gap is kept constant. All cases exhibit a non-symmetric flow behavior in the mid-frontal plane. As compared with the baseline, significant negative pressures were found acting on the TVFs when the false glottal width is below a certain threshold value. The closing forces are increasing when the FVFs are located at larger distances further downstream from the TVFs.

1:20

5pSC2. Production of child-like vowels with nonlinear interaction of glottal flow and vocal tract resonances. Brad H. Story and Kate Bunton (Speech, Lang., and Hearing Sci., Univ. of Arizona, 1131 E. 2nd St., P.O. Box 210071, Tucson, AZ 85721, bstory@email.arizona.edu)

Acoustically, the mechanisms of vocal sound production may be considered to exist along a continuum. At one end, the glottal flow wave is weakly coupled to the resonances of the vocal tract such that the output is a linear combination of their respective acoustic characteristics, whereas at the other end there is strong nonlinear coupling of the flow source to the vocal tract resonances. To express phonetic properties in the output, such as formants, the linear case requires that the source produce sound that is rich in harmonic or broadband energy. In contrast, the nonlinear case allows for the possibility of an harmonically-rich source signal to be generated even when the glottal area variation is so simple that it may contain only one harmonic (i.e., a sinusoid) [Titze, J. Acoust. Soc. Am. **123** (2008)]. The latter case is most likely to occur when the fundamental frequency is relatively high, such as in children's speech. The purpose of this study was to investigate the nonlinear end of the continuum with respect to the harmonic content of the glottal flow and pressure waveforms for vowels generated with a model of a child-like speech production system. [Research supported by NIH R01-DC011275, NSF BCS-1145011.]

1:40

5pSC3. Non-invasive *in vivo* measurement of the mechanical properties of human vocal fold tissue. Siavash Kazemirad, Hani Bakhshaei, Luc Mongeau (Dept. of Mech. Eng., McGill Univ., 817 Sherbrooke St. West, Montreal, QC H3A 0C3, Canada, siavash.kazemirad@mail.mcgill.ca), and Karen Kost (Dept. of Laryngology, McGill Univ., Montreal, QC, Canada)

The mechanical properties of the vocal fold mucosa have a great effect on the vocal folds oscillations, and voice quality. A non-invasive method was developed and examined to obtain the mechanical properties of human vocal fold tissue *in vivo* via measurements of the mucosal wave propagation speed during phonation. High speed and MRI images of three subject's vocal folds were captured while phonating at different pitches. The images obtained from these two techniques were matched and the dimensions of the vocal folds were obtained. The mucosal wave propagation speed was determined for the three subjects at different pitches through an automatic image processing procedure. The shear modulus of the subjects' vocal fold mucosa was then calculated using a surface (Rayleigh) wave propagation model and the measured wave speeds. This is revealed that the mucosal wave propagation speed and the shear modulus of the vocal fold tissue increased with the pitch. The results were in good agreement with those from other studies obtained via *in vitro* measurements, thereby supporting the validity of the proposed measurement method. This method offers the potential for *in vivo* clinical assessments.

2:00

5pSC4. Quantification of porcine vocal fold geometry in three dimensions. Kimberly A. Stevens (Mech. Eng., Brigham Young Univ., 435 Crabtree Bldg., Provo, UT 84602, kimst12@gmail.com), Marie E. Jette, Susan L. Thibeault (Div. of Otolaryngol. - Head and Neck Surgery, Univ. of Wisconsin–Madison, Madison, WI), and Scott L. Thomson (Mech. Eng., Brigham Young Univ., Provo, UT)

The geometry of the vocal folds, including the internal spatial distribution of the various tissue types, plays a central role in governing vocal fold flow-induced vibration. Quantifying the tissue geometries is therefore important for voice production research. In this presentation, quantitative measures of porcine vocal fold geometry obtained using three different techniques are reported and compared. MicroCT scans of three fresh porcine larynges were obtained with the folds in abducted and adducted positions. Adducted larynges were frozen, rescanned, cut in the midsagittal plane, and rescanned while frozen. The larynges were then thawed and the vocal folds were dissected. One vocal fold was frozen in optimal cutting temperature medium, serial-sectioned in the coronal plane, and imaged, and the other vocal fold was fixed in 10% formalin and embedded in paraffin before being sectioned and imaged. Geometrical data was obtained and compared between the different sets of histological images and the microCT images. This study provides quantitative measures of porcine vocal fold geometry and characterizes the influence of formalin fixation and histological processing on tissue deformation tissue across the three-dimensional vocal fold, leading the way for similar studies using human vocal folds.

2:20

5pSC5. Evaluation of contact pressure in human vocal folds during phonation using high-speed videoendoscopy, electroglottography, and magnetic resonance imaging. Zhe Li, Hani Bakhshaee (Mech. Eng., McGill Univ., #305 3650 de la montagne, Montreal, QC H3G2A8, Canada, zhe.li2@mail.mcgill.ca), Leah Helou (Commun. Sci. and Disord., Univ. of Pittsburgh, Pittsburgh, PA), Luc Mongeau (Mech. Eng., McGill Univ., Montreal, QC, Canada), Karen Kost (Otolaryngol. - Head and Neck Surgery, McGill Univ., Montreal, QC, Canada), Clark Rosen (Voice Ctr., Univ. of Pittsburgh Medical Ctr., Pittsburgh, PA), and Katherine Verdolini (Commun. Sci. and Disord., Univ. of Pittsburgh, Pittsburgh, PA)

Mechanical stresses on the vocal folds surface during high pitch or amplitude phonation have been postulated to cause vocal fold damage. Models for the quantitative estimate of the contact pressure may be valuable for prevention and treatment. The objective of this study was to non-invasively estimate the contact pressure for different phonation types, amplitudes, and pitch in human subjects using concurrent high-speed videoendoscopy and eletroglottography. The edge velocities before and after contact were estimated from the analysis of consecutive digital images. Instantaneous contact areas were determined from electroglottography along with magnetic resonance image (MRI). The contact pressure was assessed using the impulse momentum form of Newton's second law. Quantitative verifications using silicone models were made. Investigations were then carried out in quantitative human subjects to compare contact pressures for three different voice types, pitches, and loudnesses. Contact pressures for breathy, normal, and pressed voice were obtained for fifteen female subjects. The results were verified through comparisons with values measured directly using a probe microphone. The proposed methods appear to be robust and accurate for contact pressure estimation.

2:40

5pSC6. Development of a small film sensor for the estimation of the contact pressure of artificial vocal folds. Sandra Weiss, Alexander Sutor, Stefan J. Rupitsch (Chair of Sensor Technol., Friedrich-Alexander-University Erlangen-Nuremberg, Paul-Gordan-Str. 3/5, Erlangen 91052, Germany, sandra.weiss@lse.e-technik.uni-erlangen.de), Stefan Kniesburges (Inst. of Process Machinery and Systems Eng., Friedrich-Alexander-Univ. Erlangen-Nuremberg, Erlangen, Germany), Michael Doellinger (Dept. of Phoniatrics and Paediatric Audiol., Univ. Hospital Erlangen, Erlangen, Germany), and Reinhard Lerch (Chair of Sensor Technol., Friedrich-Alexander-Univ. Erlangen-Nuremberg, Erlangen, Germany)

Since voice production is the precondition for speech and, therefore, verbal communication, people suffering from voice disorders are limited in their everyday life. Physiological voice disorders, like vocal fold nodules are understood to result from increased contact pressure of the vocal folds during vibration. Thus, measurement of arising contact pressure during vocal fold oscillation helps quantify the collision forces and to substantiate previous assumptions. Due to limited access to the vocal folds, there is need for a small sensor that minimally influences air flow. For that purpose, we developed a small film sensor which is capable of measuring the contact pressure along the vocal fold contact areas. To investigate the suitability of the sensor, a hemi-larynx flow channel experiment with silicone replicas of the vocal folds was performed. Replicas of different elasticities were investigated. The contact sensor signals as well as the subglottal pressure were acquired. High-speed recordings of the vocal fold oscillation were synchronously performed to accurately relate the opening, closing and contact phases to the time signals. The measured contact pressures will be reported and compared to previous results. The advantages and limitations of the developed sensor will be discussed.

3:00

5pSC7. Dynamics of supraglottal flow structures and sound generation in phonation. Stefan Kniesburges, Christina Hesselmann, Stefan Becker (Inst. of Process Machinery and Systems Eng., Univ. of Erlangen-Nuremberg, Cauerstrasse 4, Erlangen, Bavaria 91058, Germany, kn@ipat.uni-erlangen.de), and Michael Döllinger (Phoniatrics and Pediatric Audiol., Univ. Hospital Erlangen, Erlangen, Germany)

Within the fully coupled multi-physics process of phonation the fluid flow plays an important role in the sound production. Therefore, the study addresses phenomena in the flow downstream of synthetic self-oscillating vocal folds and their influence on the sound production. A test setup consisting of devices for producing and conditioning the flow including a test section was used. The supraglottal channel was developed to prevent acoustic coupling to the vocal folds. Hence, the oscillations were aerodynamically driven. The vocal folds consist of silicone rubber having homogeneous material distribution. The flow was visualized in the immediate supraglottal region using a laser-sheet technique and a highspeed camera. The flow shows asymmetric behavior in cases with channel. The glottal jet is bend to one side depending on the turbulent flow conditions in the channel. In cases without channel, the jet was stabilized by the constant ambient pressure being symmetrical at each instance during an oscillation cycle. Additionally, the acoustic response of the studied supraglottal cases was investigated in an anechoic chamber. The spectral analysis of the data turns out differences in tonal and broadband parts of the acoustic spectrum. The context to the visualized flow structures will be discussed.

3:20

5pSC8. Acoustic perturbation equations and Lighthill's acoustic analogy for the human phonation. Stefan Zoerner (Inst. of Mech. and Mechatronics, Vienna Univ. of Technol., Wiedner Hauptstrasse 8-10, Vienna 1040, Austria, stefan.zoerner@tuwien.ac.at), Petr Šidlof (Inst. of Thermomechanics, Acad. of Sci. of the Czech Republic, Liberec, Czech Republic), Andreas Hüppe, and Manfred Kaltenbacher (Inst. of Mech. and Mechatronics, Vienna Univ. of Technol., Vienna, Austria)

In speech, air is driven through the larynx by compression of the lungs. Thereby, air flows through the glottis which forces the vocal folds to oscillate which in turn results in a pulsating air flow. This air flow is the main source of the generated sound—the phonation. The acoustic wave then passes through the vocal tract, which acts as a filter modulating the propagated sound leaving the mouth. We model the fluid-structure-acoustic interaction with a so called hybrid approach. The air flow in the larynx, together with a prescribed vocal fold motion, is simulated with help of the open source solver OpenFOAM. Based on the resulting fluid field, acoustic source terms and the wave propagation is calculated within the finite element solver CFS++. Two methods are available to choose from, Lighthill's acoustic analogy and an aeroacoustic analogy based on a perturbation ansatz. Additionally, the simulation domain is extended by a realistic but geometrical fixed vocal tract and connected to a propagation region. The different acoustic approaches are compared, by analyzing the acoustic pressure in the glottis (source region) and outside the vocal tract. Moreover, to illustrate the effects of the vocal tract an alternative geometry is used for comparison.