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## Distributed Immersive Performance: Ameliorating the Psychophysical Effects of Network Latency

PRESENTERS

*Elaine Chew, Alexander Sawchuk, Roger Zimmermann*
*University of Southern California Viterbi School of Engineering*
*Integrated Media Systems Center*

COLLABORATORS

*Tosheff Piano Duo (Vely Stoyanova, Ilia Tosheff),*
*Chris Kyriakakis, Christos Papadopoulos,*
*Alexandre François, Anja Volk*

PRESENTERS' SHORT BIOGRAPHIES

Elaine Chew is an Assistant Professor at the University of Southern California Viterbi School of Engineering, where she is affiliated with the Epstein Department of Industrial and Systems Engineering and the Integrated Media Systems Center (IMSC). She is a recipient of a 2004 NSF Career award and was recently appointed the User-Centered Sciences Research Area Director at IMSC. Dr. Chew received her SM and PhD in Operations Research from the Massachusetts Institute of Technology, and a BAS in Music and Computational Mathematics from Stanford University. Her principal research interests lie in the design and application of computational models and algorithms for problems in music perception and cognition.

Alexander A. Sawchuk received the S.B. from the Massachusetts Institute of Technology, and the M.S. and Ph.D. from Stanford University, all in electrical engineering. He is Professor in the Department of Electrical Engineering and Deputy Director of the Integrated Media Systems Center at the University of Southern California. He is a Fellow of the Optical Society of America (OSA), the Institute of Electrical and Electronics Engineers (IEEE), and the International Society for Optical Engineering (SPIE). He received the OSA Distinguished Service Award and the Halliburton Award for Exceptional Service, the Lockheed Senior Research Award, and the TRW Outstanding Teaching Award from the USC Viterbi School of Engineering. His research includes image processing, acquisition and display, and optoelectronic data storage and network systems. He is the holder of a U.S. Patent and is the author or co-author of more than 160 technical publications and 100 talks in these fields, including several books and book chapters.

Roger Zimmermann is a Research Assistant Professor with the Computer Science Department at the University of Southern California. He is also a Research Area Director with the Integrated Media Systems Center (IMSC). He received his BS in Informatics from the Fachhochschule Aargau, Switzerland, and MS and Ph.D degrees in Computer Science from the University of Southern California, Los Angeles. His research interests are in the area of streaming media and peer-to-peer architectures, immersive environments, and multimodal databases. Two of his recent projects are HYDRA, a scalable real-time streaming system supporting live, high-definition video transmissions and the Remote Media Immersion (RMI) platform.

DETAILED ABSTRACT/OUTLINE

The Distributed Immersive Performance (DIP) project explores one of the most challenging goals of networked media technology: creating a seamless environment for remote and synchronous musical collaboration. A number of research groups have presented one-time demonstrations of distributed performance with varying degrees of success since the 1970s. None, as far as we know, has focused on capture and recording of musical experience and thorough analysis of realistic musical interaction in an environment constrained by network latency and reduced physical presence. We further take on the challenge of developing metrics for measuring the psychophysical and perceptual effects of performing under such conditions so as to determine the thresholds for usability and bottlenecks for improved human interaction in remote collaborative environments. By understanding the psychophysical effects of latency on synchronous collaborative performance, we progress towards the designing of better systems for enabling effective collaboration over distance.

First, we present a comprehensive framework for the capture, recording and replay of high-resolution video, audio and MIDI streams in an interactive environment for collaborative music performance. Our target is the creation of the complete aural and visual ambience that places a person or a group of people in a virtual space where they can experience events occurring at a remote site or communicate naturally regardless of their location. Our objective is to reproduce this ambience with realism approaching the limits of human perception. The DIP experimental system has interaction sites and servers in different locations on the USC campus. Each site is equipped with high-definition (HD) video or digital video (DV) quality images projected onto wide screen wall displays completely integrated with an immersive audio reproduction system for a seamless, fully three-dimensional aural environment with the correct spatial sound localization for participants. The system is capable of storage and playback of the many streams of synchronized audio and video data (immersidata), and utilizes novel protocols for the low-latency, seamless, synchronized real-time delivery of immersidata over local area networks and wide-area networks such as Internet2.

Next, we present initial results from our experiments for determining the effects of latency in auditory feedback on performers' satisfaction with the ease of creating a tight ensemble, a musical interpretation and adaptation to the conditions. These experiments mark the beginning of our efforts to study systematically the effects of musical interaction over the Internet in a realistic performance setting. The three experiment scenarios are: (A) two players in the same room at separate keyboards with direct visual contact and delayed auditory feedback from partner; (B) the same experiments with players swapping parts; and, (C) players performing with direct visual contact and delayed auditory feedback from partner AND self. The users and evaluators of the system are the Tosheff piano duo, consisting of Vely Stoyanova and Ilia Tosheff, a professional piano duo who have won awards and concertized internationally. User responses are reported for experiments using Poulenc's "Sonata for Piano Four-Hands", where the movements are *Prelude* (score-recommended tempo of 132 bpm), *Rustique* (46 bpm) and *Final* (160 bpm). The musicians were asked to rate their ease of creating a tight ensemble, ease of creating a musical interpretation, and their assessment of whether they could adapt to each given condition.

The two players' ratings did not differ very much in the first two scenarios (A and B): for the fast movements (one and three), the players experienced the highest difficulty in creating a tight ensemble at 50 ms and above. In the fast but not-so-rapid first movement, the players almost always rated difficulty in creating a musical interpretation higher than ensemble (synchronization) difficulties. In general, the duo judged that, with practice, they could adapt to delays below 50 ms. At the request of the Tosheff Duo, who expressed a desire to experience the audience's auditory perspective, we created Scenario C, where each player received delayed feedback from their own playing synchronized with the delayed auditory feedback from the other player. Both players greatly preferred scenario C over A or B. In Scenario C, the players felt that they could rely on their ears to adjust their playing so as to produce the best performance possible. Furthermore, the adaptability threshold for Scenario C was 65ms, higher than the 50ms for Scenarios A and B.

Our experience with the Tosheff Duo leads us to hypothesize that in the performing of synchronous collaborative tasks in distributed environments where network delay is unavoidable, users may be willing to tolerate and adjust to delayed feedback of their own actions in order to achieve the experience of a common perspective. This common perspective, in turn, enables the forming of common goals, and strategies for achieving them, thus resulting in a more satisfying and successful cooperative experience.

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