Scanning the Issue

Special Issue on Engineering and Music—Supervisory Control and Auditory Communication

I. Engineering and Music—A Transdisciplinary Connection

Many engineers can profit by understanding the promising trends and exciting new technologies in the transdisciplinary domain of *engineering and music*. Today, we can learn from music much more than we originally thought possible for engineering applications. The important topics covered in this Special Issue are *supervisory control* and *auditory communication* for human–system interaction, cooperation, and control. Furthermore, engineers are often fascinated by the tradition-rich cultural and scientific areas of music. People such as Helmholtz, Le Caine, Bell, Dudley, and others have either been influenced or derived inspiration from results in music research. Areas such as spectral analysis, the mathematics of music, human–computer interaction, and other areas have been influenced by music.

The topics of *engineering* and *music* have been interrelated since ancient times in many cultures. Making musical instruments, generating and transmitting sounds, and investigating acoustics are all based on music and engineering knowledge, creativity, and craftsmanship. The advent of electrical machines and instruments since around 1900 opened new avenues for cooperation between engineers and musicians. These can be regarded as the first landmarks for electronic music, which continued to prosper in the 1920s and 1930s [1]. An intensified development and the subsequent birth of computer music occurred in the 1950s [1]–[3]. Many laboratories and studios have been founded worldwide since then. The further developments of electronic and computer music have intensified the possibilities for collaborations among engineers, computer scientists, psychologists, musicologists, and musicians. Additional contributions have been provided by the fields of acoustics [4] and communication science [5]. All these endeavors compose the area of *auditory communication* in the widest sense.

New technologies for human–system symbiosis are emerging in engineering and music sciences. Cooperation, communication, and control for better human–system symbiosis lead to improved interactive products and systems—in industrial process control, in vehicular guidance, in medical engineering, in telerobotics, and in the service sectors, as well as in broad areas of the music, film, and television industries. *Supervisory control* is regarded as guidance, through humans, of computerized technological systems as well as of human-cooperative systems [6]–[8]. *Auditory communication* provides increasingly important means for supervisory control which are required in real multimodal and multimedia environments. Gestural control has recently been recognized as an interconnecting field of research [9].

The classic book by Cherry, *On Human Communication* [5], is still a brilliant overview and introduction into communication science. Human communication includes the capability of recognition. This is particularly also true for auditory communication. The recognition process is especially needed when knowledge and information has to be retrieved from huge library stores in which much of our cultural heritage is held. Information retrieval can be investigated with cognitive systems engineering methodologies [10]. Musical information retrieval turns out to be a particularly challenging subset.

A transdisciplinary approach of engineering and music with several interrelated areas of research and applications has been pursued with an innovative international workshop and its subsequent publications. This workshop, "Human Supervision and Control in Engineering and Music," was held in Kassel, Germany, in September 2001. It was organized in one stream of lectures, discussion sessions, interactive orchestra rehearsals, and a scientifically embedded orchestra concert with works by Copland, Takemitsu, Nagashima, and Beethoven. About 50 scientists, mainly from Europe, North America, and the far East (especially Japan), represented different fields of the two domains of engineering and music and explored their common theoretical and practical foundations in human supervision and control. Engineering, information, and cognition scientists from the knowledge domain of engineering represented the fields of human–computer interaction; human–machine systems research; multimedia, audio, and music technologies; knowledge-based systems; perception psychology; and cognitive system science. Musicologists and musicians from the

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knowledge domain of music came from the fields of music theory, composition, media composition, computer music, conducting, and interpretation. The online proceedings have been published [11].

The domain of human supervision and control can be analyzed in the engineering sciences and in musicology from different cultural, social, and intellectual perspectives. It embraces the human activities of guidance, monitoring, and control (manual and supervisory control or sensorimotor and cognitive control) and also includes perception, information processing, and action. *Supervisory control* is methodically the most important subdomain of human supervision and control. Other subdomains supplement this with respect to different aspects of the creation and transfer of information, such as gestural control, motion and sound control, information retrieval, composition and analysis, sound design and multimedia, virtual environments, performance, and interpretation, as well as visual, auditory, and haptic supervision and communication.

Two Special Issues have been derived, mainly by selecting and strongly reviewing papers, from the international workshop "Human Supervision and Control in Engineering and Music." The first Special Issue, with ten papers, appeared in the *Journal of New Music Research* [12]. After an overview and introductory article by this author, the nine other papers represent and focus on the areas of composition and analysis, performance, and interpretation, as well as sound design, auditory display, and multimedia, with respect to human supervision and control in music. Other themes of the workshop with a more engineering-orientated view are covered within this Special Issue of the PROCEEDINGS OF THE IEEE. The 13 articles of this Special Issue can be categorized into three groups: 1) supervision, control, and performance; 2) gestural control, sound synthesis, and interactive multimedia; and 3) music information retrieval and auditory display. The succeeding sections provide a brief introduction and outline of these three categories and of all 13 articles.

II. SUPERVISION, CONTROL, AND PERFORMANCE

The first four papers deal with the cooperation between humans and systems. They address supervisory control in music and engineering, team organization, and performance. The similarities and dissimilarities of supervisory control in music and engineering are discussed. Control, coordination, and improvization in teams are analyzed.

In "Human Supervision and Control in Engineering and Music: Similarities, Dissimilarities, and their Implications," T. Inagaki and J. Stahre use the human supervisory control paradigm to compare industrial and musical systems. Human supervisory control of complex engineering systems is introduced with a hierarchy of parallel interactive computers (for carrying out tasks) and a coordinating computer (dealing with human interaction). Five phases of the human's supervisory control effort are distinguished: planning, teaching, monitoring, intervening, and learning. The authors discuss how this model can be applied in engineering and in music. The examples of an orchestra and of a technical or industrial system are compared with respect to several supervisory control aspects. The similarity of dealing with unplanned events and control versus spontaneity and creativity has been investigated. Dissimilarities too have been identified from the viewpoints of transmission of situational and intentional information, and authority for cooperative work. The paper identifies valuable knowledge and experience which can be learned from the music field for engineering. The perspectives of intelligence to understand the intent of other agents, as well as authority and decision making, and action implementation have been analyzed. The authors conclude that the general applicability of the human supervisory control model is a key issue for successful knowledge transfer between the musical and the engineering domains.

The next paper, "Musings on Music Making and Listening: Supervisory Control and Virtual Reality" by T. B. Sheridan, applies the human supervisory control paradigm for viewing music making as a three-level hierarchy of control and feedback interactions. At the top level, a composer, conductor, or teacher is "programming" another human to play an instrument. The middle level is internal to the musician where a human is programming his or her own body to play an instrument; thus, the higher brain centers interact with the subconscious neuromuscular activity. At the lowest level, the musician's neuromuscular system interacts with the musical instrument. Sheridan discusses the functioning and the constraints of each level. In a second perspective of the paper, music listening is considered as, and compared with, virtual reality and virtual presence, with implications for research to better understand human emotional reactions to music.

"Teamwork in the Performing Arts" by W. B. Rouse and R. K. Rouse is the third paper. The nature of teams and teamwork is addressed, partially in the context of supervisory control. The paper provides an overview of a range of research into team performance. It includes results for business and operational teams, as well as selected studies of performing arts teams. An interview study has been carried out with performing arts leaders in symphony and chamber orchestras, chorus, and jazz, as well as musical theatre, straight theatre, improvization, ballet, and puppetry. The results suggest an "ecology" of performance. The characteristics of this ecology strongly influence the nature and roles of teams, as well as how teams are created and supported. The excellence of performance in the arts is often dominated by the quality of collaboration among team members. The mental models associated with individual performance are assumed to be developed when team members are selected. The conclusions of the paper represent well-informed hypotheses more so than empirical facts. It is argued that invention and innovation in the arts and in technology involve quite similar psychological and social processes.

In "Human–Technology Interaction and Music Perception and Performance: Toward the Robust Design of Sociotechnical Systems," A. Kirlik and S. Maruyama present a common theoretical framework for investigating perception, performance, control, and coordination in both domains of engineering and music. The approach is based on Brunswik's theory of probabilistic functionalism, and describes the challenges which have to be faced by both musicians and operators of technological systems. The framework represents relations between perception and action. With perception, musicians and operators must accurately infer states from available information (e.g., inferring the emotional meaning of a musical composition; inferring the functional meaning of interface displays). Then, both must select available actions or means to achieve ends or goals (e.g., a conductor using hand movements to direct an orchestra; an operator using interface controls to tune an industrial process or respond to a fault). The approach is illustrated with a review of perception and performance research on both music and human–technology interaction under this perspective. The authors present their own study of the coordination between a professional conductor's hand movements and a concert master's bowing actions. The paper concludes with an evaluation of the prospects for additional studies of group musical performance to yield new insights into designing more effective and robust sociotechnical systems.

III. Gestural Control, Sound Synthesis, and Interactive Multimedia

Another area of music which provides new ideas for human–machine systems is concerned with gestural control and various input devices, particularly for musical instruments. Two completely different kinds of gestures can be distinguished, those of conductors and those of instrumentalists. The gestures created by arm, hand, and finger movements of the conductor convey the cognitive and the emotional representations of musical content along different parallel time scales in order to initiate and guide a synchronized and expressive team performance of the orchestral musicians. The question arises as to whether it would also be possible to "conduct" a power plant, a truck, or a real-time software application. Again, this refers also to the previous section on more flexible human–system cooperation.

The gestures executed by the instrumentalists are of various types. On the one hand, there are those gestural movements of the musicians which are directly related to the production of sounds. On the other hand, there exist several types of gestures which do not obviously correlate with the immediate production of sound. However, they contribute in subtle ways to the quality and expressiveness of sounds, and thus to their deeper content and meaning. A good deal of research is devoted to the investigation of all these different kinds of gestures, gestural control, and sound synthesis, as well as related applications of interactive multimedia, new interfaces, and performance.

In the paper "Gestural Control of Sound Synthesis," M. M. Wanderley and P. Depalle provide an extensive review of this field of research in the context of the design and evaluation of digital musical instruments. The developments in this context are particular driving forces for better understanding of gestures and gestural control in music but also in general human–computer interaction applications. The paper discusses the subject by equally focusing on four topics: analysis of musical performers' effective and expressive gestures, gestural capture technologies using sensors and through the analysis of the sound generated by an acoustic instrument, real-time sound synthesis methods, and strategies for mapping gesture variables to sound synthesis input parameters. The authors suggest that a balanced approach taking into account these four topics can improve the design of novel digital musical instruments. A detailed example of application illustrates the possibilities of improving the control of digital audio effects through information obtained from the analysis of a clarinetist's expressive movements and the real-time modeling of the acoustic effects of these movements. Generally, the authors view gestural control of computer generated sound as a highly specialized branch of human–computer interaction involving the simultaneous control of multiple parameters, timing, rhythm, and user training.

K. C. Ng presents a framework in the paper "Music via Motion: Transdomain Mapping of Motion and Sound for Interactive Performances." The mapping between physical movements of the performers and multimedia events is described. Activities from one creative domain to another are translated, e.g., from physical gesture to audio output. The music via motion framework consists of five main modules, for data acquisition, motion tracking, multimedia mapping, graphical user interface, and multimedia output respectively. A number of implementations and key studies for inter- and multidisciplinary collaborative works of interactive multimedia performances have been developed. One project is designed with the collaboration of multiple creative domains for integrating special costumes, music, and dance within an interactive audiovisual performance interface simulated by the music via motion framework. The interactive music head explores facial expression tracking, aiming to create an aesthetic talking head intended for mediating interaction between humans and machines. The augmented drum uses sensors to provide additional multimedia control for the player. Ongoing developments deal with expressive motion analysis and explorations on stage augmentation with virtual and augmented realities.

In the paper "Robotic Interface for Embodied Interaction via Dance and Musical Performance," K. Suzuki and S. Hashimoto propose a substantial robotic interface for collaborative work between humans and machines in a multimodal musical environment. This interface is regarded as a "moving instrument" that displays the reactive motion on a stage while producing sound and music according to the context of the performance. The authors explain four case studies with musical platforms utilizing robotic and information technologies in different ways. These four case studies are characterized along the two axes of autonomy and embodiment of the robot as well as direct and indirect response within a human–machine environment. The developed robotic systems are a reactive audiovisual environment, a visitor robot, a dance platform that is a semiautonomous human cooperative robot, and an autonomous robot for music-based human–machine interaction. The four mobile robot platforms create multimodal artistic environments for music and dance performance. They reflect visual and auditory information around the human and the robot. As the humans can convey their intentions to the robot by actions, a new style of music generation with an autonomous mobile ability has been realized. The authors are convinced that the system works as an emotion activator stimulating human creativity.

Another paper on musical instrument design and human–computer interaction has been provided by S. S. Fels, titled "Designing for Intimacy: Creating New Interfaces for Musical Expression." Again, the mapping between gesture and sound has been designed for effective and expressive musical instruments. Four types of relationships between the musician or player and his instrument, and the aesthetics of these relationships, are discussed in the paper. A high degree of intimacy is achieved when the mapping between control and sound is transparent to the player; thus, the player embodies the instrument. Ultimately, this type of relationship allows intent and expression to flow through the player to the sound, with a high possibility for creativity. Three works illustrate the concepts of high intimacy and embodiment for satisfying expressive experiences. The iamascope is an interactive art work which maps the player's movements to sounds and images by using a video camera. The sound sculpting tool allows sound space navigation with the metaphor of object manipulation. Those parts of the mapping between manipulation and sonification which can be more easily explained make it easy for a player to create a mental model and, thus, support the formation of intimacy. The author indicates that the choice of metaphor is important for this formation. The third instrument is the tooka, a two-person instrument. The intimacy requires a high level of close communication between two players. This effort may lead to powerful modes of expression which are not possible with single-person instruments. The author concludes from the design and the evaluation of these three works/instruments that not only are new music synthesis techniques and new sensing technologies needed for improved musical instrument design, but also better understanding of human–computer interaction and new techniques for measuring intimacy.

In the paper "Modeling and Control of Expressiveness in Music Performance" by S. Canazza *et al.*, the important aspect of expression of musical performance is highlighted. The paper provides a good review of the concepts, problems, and state of the art. The authors believe that understanding and modeling expressive content communication can be exploited for many engineering applications in information technology. A more sophisticated range of multimedia products will be achieved with a more intensive use of digital audio effects which allow the user to interactively adapt sounds to different situations. The paper presents an original approach to gradually modifying the expressive content of a performance, both at symbolic and signal levels. A model is discussed which applies a smooth morphing among different expressive intentions in music performances, adapting the expressive character to the human desires. Based on the analyses of many performances, a multilevel representation has been designed which is robust with respect to morphing and rendering of different expressive intentions. The sound rendering is obtained by interfacing the expressiveness model with a dedicated postprocessing environment. This allows the transformation of event cues, based on the organized control of basic audio effects. Among these, an original method for the spectral processing of audio is introduced. The authors demonstrate that a good modeling of expressive performances has been reached, and both the understanding and focusing of topics related to the communication of expressiveness has been augmented.

IV. Music Information Retrieval and Auditory Display

The last four papers of this Special Issue deal with application-oriented aspects of auditory communication. The importance of musical information retrieval is covered in the next two papers. Then, the last two papers exemplify auditory display for large data sets and for human–machine interfaces, respectively.

In "Emotional Image and Musical Information Retrieval with Interactive Genetic Algorithm," S.-B. Cho presents an approach that implements image and music retrieval systems with human preference and emotion using an interactive genetic algorithm. This algorithm and several music retrieval systems are briefly introduced. A preliminary study of image retrieval provides a better understanding of the potential of the interactive genetic algorithm, before the musical information retrieval system is illustrated. Both systems enable the users' subjective retrieval of images and music by the evolutionary generation of appropriate queries through the interaction with the users. Quite different retrieval environments have been created as compared to conventional systems which search indices based on classification and compare extracted patterns. Novice users can find images and music that they want without knowing the exact title, composition, or melody. The interactive genetic algorithm performs optimization with human evaluation, and the user can obtain what he has in mind through repeated interactions. Objective measures of music interval variation and the power spectrum of frequency are combined with subjective characteristics of emotion. Corresponding emotional human–computer interfaces have been developed. On the basis of several experiments and their results, the author expects that the same approach can be applied to many other problems in musical information retrieval and manipulation based on intuition and inspiration.

In the paper "Musical Instrument Classification and Duet Analysis Employing Music Information Retrieval Techniques," B. Kostek presents solutions related to identifying musical data on the basis of several experiments. The author provides an intensive overview on the importance of expert knowledge in musical information retrieval systems. Then, she presents an automatic classification of musical instruments and a particular application to the separation of duet sounds. The classification process is shown as a three-layer process consisting of pitch extraction, parameterization, and pattern recognition. These three stages are discussed on the basis of experimental examples. Artificial neural networks are employed as decision systems and are trained with a set of feature vectors. For the musical duet analysis, the frequency envelope distribution algorithm has been introduced. The artificial neural networks are also used for checking the efficiency of the frequency envelope distribution algorithm. The experimental results for sound separation are shown and discussed. The experiments and algorithms investigated in this paper are an important part of the larger musical information retrieval domain, which aims at automatic retrieval of complex information from musical databases.

The paper "Sound and Meaning in Auditory Data Display" by T. Hermann and H. Ritter explores new ways of interacting with complex data sets. Semantic content of data is made perceptually accessible by nonverbal audible sound. The authors discuss the issue of encoding meaning from the perspectives of language, music, functionality, listening modes, and physics. A new framework of model-based sonification is introduced with a natural semantic grounding in the physics of the sound generation process. The model-based sonification approach is illustrated with an example using particle trajectories for sonification. This approach also facilitates the design of an intuitive, active navigation with acoustic feedback. The first prototype of a tangible sonification interface allows the perceptual mapping of the user's exploratory hand motions into sound. A haptic interface ball has been developed for controlling and interacting with the sonification models. It provides a user interface for direct haptic interaction with high-dimensional data sets. It can be squeezed, shaken, rotated, and otherwise influenced by corresponding control inputs on and within the ball. Acoustic feedback provides the user with the illusion that the data are inside the ball. Finally, the authors hope that the method can stimulate the invention of new sonification models.

The paper "Auditory Displays in Human–Machine Interfaces" by G. Johannsen provides an overview and classification of auditory displays for use in human–machine systems. The classifications are based on application, user, and sound orientation. The author also describes the participative or user-centered design process for auditory displays. The domain of mobile service robots has been chosen as an example of the future use of auditory displays within multimedia process supervision and control applications. In the design of nonspeech auditory displays, the rich body of knowledge from music theory as well as from auditory science and sound engineering has been exploited. Directional sounds and additional sounds for robot states as well as more complicated robot sound tracks have been created. Basic musical elements and robot movement sounds have been combined for these designs. Two exploratory experimental studies are described in the paper, one on the understandability of directional sounds and the robot state sounds, and the other on the auditory perception of intended robot trajectories in a simulated supermarket scenario. The experimental results include subjective evaluations of sound characteristics such as urgency, expressiveness, and annoyance. The author concludes that the need for auditory displays, and thereby the demand for task- and user-oriented sound design, will increase in many application domains in the near future.

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