STRUCTURAL FEEL OR FEELINGS FOR STRUCTURE?

Stirring Emotions through the Computer Interface in Behaviour Analysis of Building Structures

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1. INTRODUCTION

The use of computers in the analysis of building structures has at present become indispensable and fairly routine. Researchers & professionals in architecture and engineering have taken advantage of current computer technology to develop richer and more comprehensive interactive interfaces in systems designed to analyse structural behaviour. This paper discusses a research project which attempts to further enrich such computer interfaces by embodying feeling or emotion (also at times referred to as affect) components into them through the use of sound and music, and the effects of incorporating these into multimodal learning modules for students of architecture at the University of Hong Kong.

Computer aided structural analysis is most often used to determine the final state of a structure resulting from full or pattern loading, but it can also be used very ably to depict the time-history behaviour of a structure resulting from dynamic or continuously incremented loads. The latter process of behaviour can provide very useful insights on structural response and it's time-dependent nature provides an excellent opportunity to incorporate emotions or feelings associated with musical or acoustic cues for added emphasis and reinforcement. This is made even more significant by the fact that studying time-history behaviour of structures is a vital part of classroom learning. This potential in the educational environment is in contrast to the confines of professional engineering practices where these cues may not be as useful or desirable because oftentimes intermediate time history data is bypassed as a procedural blackbox and focus is placed primarily on bottomline analysis results.

The paper will discuss the basis for the use of musical and acoustic cues in this project as well as it's implementation-which consists mainly of two parts. The first involves 'personifying' the structure by putting in place a structure monitoring system analogous to human vital signs. The second involves

CAADRIA '98 : Proceedings of The Third Conference on Computer Aided Architectural Design Research in Asia.
eds. T. Sasada, S. Yamaguchi, M. Morozumi, A. Kaga, and R. Homma
April 22-24, 1998. Osaka University, Osaka, Japan. Pp. 163-171

setting up a 'ladder' of emotion states (which vary from feelings of serenity to those of extreme anxiety) mapped to the various states of a structures stability or condition. The paper will further elaborate on how this is achieved musically through the use of percussion, motifs, and harmonic/rhythmic patterns in resonance with relevant graphical animations.

Initially in this project, emotion cues were used to reinforce two structural behaviour tutoring systems developed by this author (3D Catenary Stuctures module & Plastic Behaviour of Semi-rigid Steel Frames module). These modules were ideal for implementing these cues because both depicted nonlinear structural behaviour in a mainly time-history oriented presentation. A brief demonstration of the actual learning modules used in the project study will also be presented together with a discussion of it's use in actual classroom teaching.

2. THE LIFE OF A STRUCTURE

Musical or acoustic cues (and the associated emotions or feelings) are integrated into the structural behaviour tutoring systems developed for this project through simulated time-history response of structures, or the life of a structure as I would like to call it. One of the effective ways for depicting structural behaviour to students of architecture and engineering is through a simulated collapse of a structure. A simulated collapse could be presented as a scaled temporal process wherein a structure undergoes initial and subsequently incrementally increasing loads until a collapse mechanism is attained. For complex redundant structures, behaviour through this process is non-linear mainly because of the the onset and recurrence of phenomena which occurs as a result of material plasticity, stress redistributions, sudden buckling, etc. It would provide students helpful insights into structural behaviour if they were to observe this process as a structure 'lives' through it's life until it collapses.

Powerful desktop computers today make it feasible, practical and convenient for even students to go beyond linear-behaviour structural analysis and move on to study non-linear behaviour of structures in real-time simulations. Advanced analysis of steel frames and cable/catenary structures are examples that require consideration for non-linear behaviour. The basic theories and analytical procedures for non-linear behaviour of such structures have been well established (e.g. Chen, Toma, 1994; Broughton, Ndumbaro, 1994).

The behaviour of steel frames in particular provide an interesting study for students. The advent of advance analysis in place of current concepts of first-order elastic, first-order plastic, and second-order inelastic analyses is significant because this method adequately represents a limit state and provides a more realistic picture of the actual behaviour of steel structures (Chen, Goto, Liew, 1996). Advanced analysis techniques are therefore an ideal basis for depicting the temporal process of simulated structural collapse.

Cable and catenary structures also make an interesting study due to their highly variable load-deflection behaviour. Portraying the temporal process of simulated behaviour of such structures under incremental loading could also lead to valuable insights into it's behaviour.

3. BIMODAL PRESENTATION OF SIMULATION

Real-time interactive simulations underpinned by more advanced, thorough, and accurate theoretical analytical models and algorithms, though much more computationally intensive, can now be realistically implemented on today's average desktop computer. Typical structural simulation computer programs now take advantage of fast graphics and animation capabilities (e.g. MacCleod, 1995). Sound however has taken a back seat to all these developments and has not really been taken advantage of to support simulations of structural behaviour except in a few applications of data sonification (Garcia, 1996, 1998). However, significant progress has been made in recent years in the area of auditory displays (earcons, sonification, audification, etc.) for scientific and general applications (e.g. Brewster, 1993).

The structural behaviour tutoring systems developed for this project presents structural simulations in a bimodal manner utilizing both the visual and audio interface.

3.1 The Visual Channel

The visual display of the bimodal interface of this system shows several key aspects of structural response of the structure as it is incrementally loaded to collapse. These consist of real-time animations of the gradual deformation of the structure, the formation and spread and distribution of plasticity, the internal force and stress distribution and redistribution, and more dramatically, buckling and collapse events.

3.2 The Audio Channel

Audio is used in resonance with the graphical display for three main reasons; first is to impart changing levels of affect (or feeling/emotion) to reflect the condition of the structure as it loses or gains stiffness and stability, second is to indicate the rate at which these changes occur, and third is to define segments or discontinuities in the structural behaviour.

4. MUSIC GENERATION

Interactive music systems have become increasingly widespread as a result of developments in multimodal/multimedia technology. Several methods and techniques for such systems have been and continue to be established (Rowe, 1993; Matthews, 1991; Nakamura, 1993). As the structural behaviour tutoring systems of this project produces real-time interactive simulations, a flexible degree of interactive music generation is required. The music is generated by parametrically filtering sequences so that short pre-composed segments can be varied along acoustic parameters like tempo, volume and timbre. Re-harmonizing and the use of harmonic and rhythmic patterns are also employed.

4.1 Emotional Response to Music

Much has been written on the association of emotion and music and a general consensus of deep interaction of the two. Several empirical studies have been made over the centuries in attempts to analyze emotional response to music (Sloboda, 1992; Dowling, Harwood, 1986; Lundin, 1967; Epstein, 1995).

Examples of such studies are those made by Scherer, Oshinsky, and Hevner. Scherer and Oshinsky studied the effects of acoustic parameters such as amplitude variation, pitch level, contour and variation, tempo, envelope, harmonic richness, tonality, and rhythm on emotional attributions (Scherer, 1995; Scherer, Oshinsky, 1977). The direction of effects as well as rating scales for emotions such as happiness, fear, anger, surprise, boredom, etc. were tabulated. The results showed that tempo of the sounds and filtration level (no. of harmonics) were very significantly the most powerful cues. Hevner studied the effects of major vs. minor modes, firm vs. flowing rhythms, complex and dissonant harmonies, rising vs. falling melodic lines on affective reactions such as agitation, excitement, happiness, serenity, etc. (Hevner, 1936).

The key emotional attributions which would have significance to the structural behaviour tutoring systems in this project are taken to range from tranquility and serenity to increasing levels of potency, anxiety, surprise and tension which would correspond to increasing levels of distress of a structure as it approaches the point of complete collapse. Based on studies made (Scherer, 1995, 1977; Hevner, 1936; Rose, 1993 Epstein, 1995) increasing levels of potency, anxiety, surprise and tension could be achieved primarily by increasing tempo and filtration cutoff (thickening timbre texture) and to a lesser degree by increasing amplitude variations, pitch contours and levels, as well as use of complex dissonant harmonies and ornamentation. These musical and acoustic qualities are integrated into the beat, melody, accompaniment and volume which comprise the music background for the structural simulations.

4.2 The Beat

The tempo of the background music for the structural simulations would be dictated by a pulse beat, a very low frequency throbbing similar to that of a human heartbeat. In the early musical tempo system developed by Johann Joachim Quantz, he designated fundamental tempo categories based on a basic speed which he designated to be the pulse rate of a healthy person in cheerful, high spirits, which would be about 80 beats per minute (Epstein, 1995). It would seem appropriate to use this as the basic pulse beat of an unloaded, unstressed structure. As the structure is loaded and internal stresses mount, tempo is increased by quickening the pulse beat thereby heightening tension and anxiety.

4.3 The Melody

The melody is generated from a selection of predefined motif sequences and transformed according to chord progression selected from preset progressions. Tension and anxiety levels are increased by increasing the number of instruments to thicken the texture. The melody is played to the tempo set by the beat. Short ornamentations are sometimes added when necessary to signal events in the simulation.

4.4 The Accompaniment

Harmony and rhythm patterns make up the accompaniment and are selected from a database which are indexed to provide different levels of tension and anxiety based on acoustic parameters discussed earlier. These are of course also played in time with the current basic tempo.

4.5 The Volume

Amplitude variations are widened to in order to increase tension and anxiety and is the only acoustic parameter that is continuous rather than discrete or stepped (in levels).

5. SYNCHRONIZATION OF STRUCTURAL BEHAVIOUR, GRAPHICS AND MUSIC

Figure 1 shows a typical load-deflection diagram of a steel frame. A typical time-history simulation would show the non-linear behaviour of the structure as loads are increased incrementally over time. Elapsed time and magnitude of applied loads are directly proportional and thus both parameters are placed on the vertical axis of the diagram. The non-linear nature of the behaviour is apparent from the diagram as plastic hinges/zones form over the structure. The formation of plastic hinges/zones are significant events in the simulated behaviour and result in loss of stiffness as well as redistribution of internal stresses. The onset of each plastic hinge therefor marks a new state for the structure, with each state shown as being subdivided in time by the dashed lines.

Increase of external forces, animation of the structural deformation, distribution of internal forces/stresses as well as the location and spread of plastic hinges/zones are portrayed graphically through the visual channel of the bimodal interface (as shown in examples in figure 2).

The audio stream or background music (figure 1) is synchronized to the visual display helps to build up levels of tension, anxiety or even frenzy in mostly stepwise increments as each plastic hinge forms. Only the volume increases continuously over time. Short insertions of musical ornamentation are played at the onset of each plastic hinge. A loud dissonant harmony is played at the point of collapse or buckling.

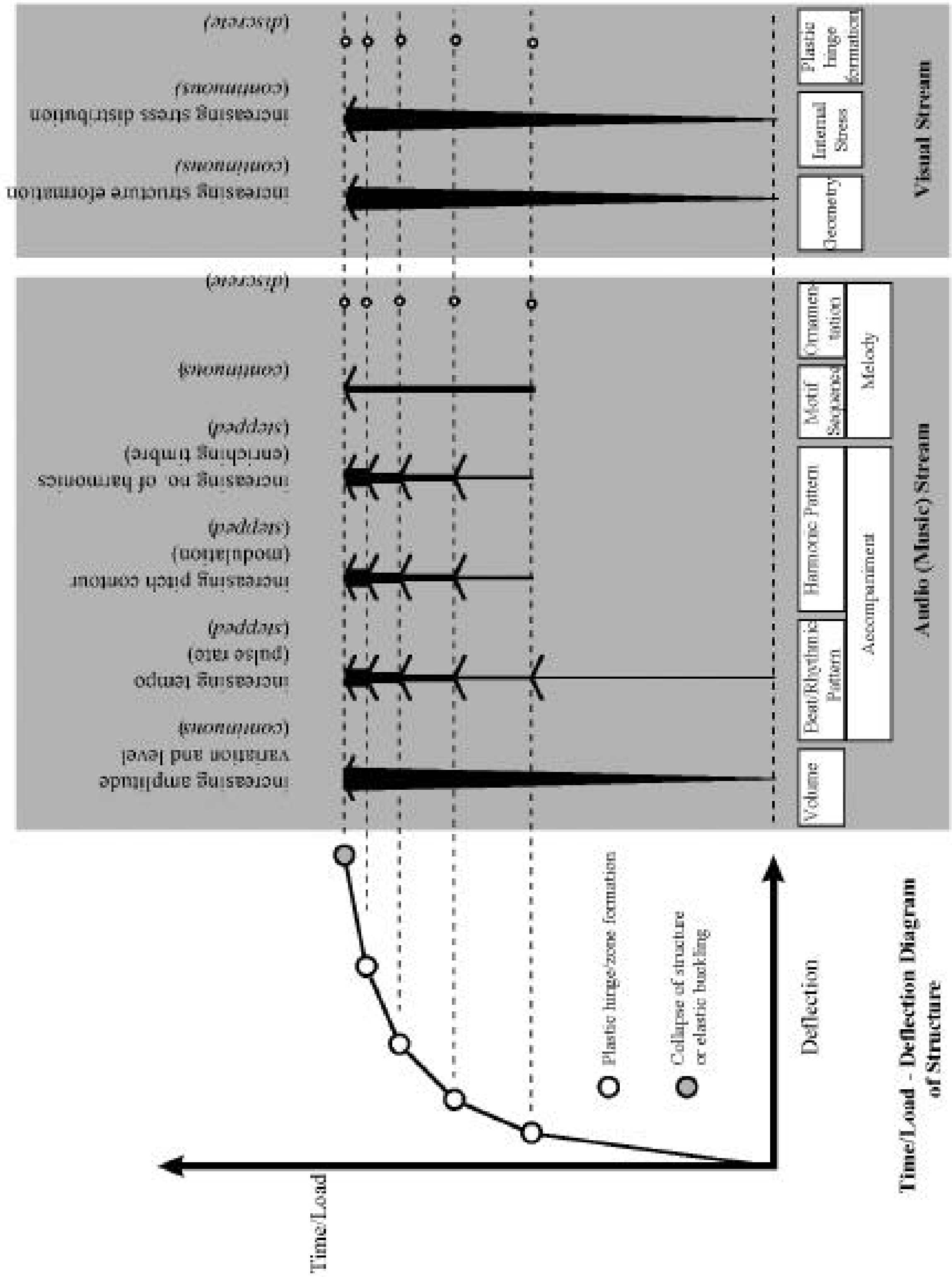
Visual Stream
Geometry
Internal Stress
Plastic hinge formation
Audio (Music) Stream
Volume
Beat/Rhythmic Pattern
Harmonic Pattern
Motif Sequence
Ornamentation
Melody
Accompaniment
Time/Load - Deflection Diagram of Structure
Deflection
Time/Load
Plastic hinge/zone formation
Collapse of structure or elastic buckling

Figure 1

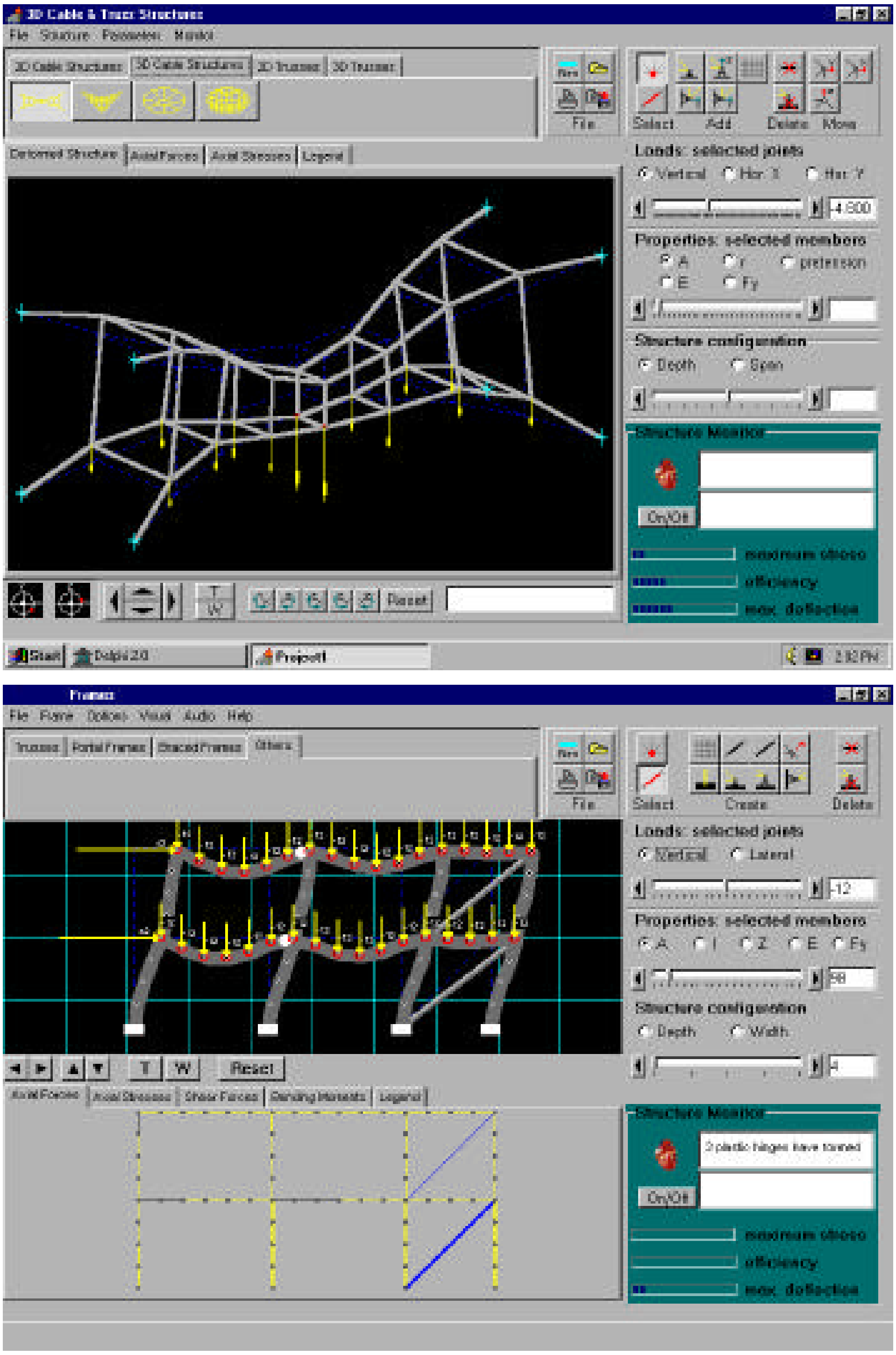
3D Cable & Truss Structures
File Structure Parameters Monitor
Deformed Structure
Axial Forces
Axial Stresses
Legend
Select
Add
Delete
Move
Loads: selected joints
Vertical
Properties: selected members
Structure configuration
Depth
Span
Structure Monitor
On/Off
maximum stress
efficiency
max. deflection
Reset
Start
Frames
File Frame Options Visual Audio Help
Trusses
Portal Frames
Braced Frames
Others
Create
Lateral
Width
Shear Forces
Bending Moments
2 plastic hinges have formed

Figure 2

6. CONCLUSION

The background music, generated during simulations by the structural behaviour tutoring systems developed for this project, forms the audio component of the bimodal interface. The music is intended only to be secondary to the visual interface and is added only for reinforcement and emphasis. The acoustic parameters are not intended to be mapped directly to structural parameters as in sonification applications but instead are taken advantage of for the affective qualities they can impart. Initial usage of the system appear to indicate that they can be effective when examining and comparing several structures in sequence in a purely quantitative and holistic manner but not when rigorous analysis is required. Further research into the effectiveness of the system in self-paced as well as in the classroom is planned.

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