Feeling the Heat

Exploring the Impact of Fire in Architectural Structures though Multimodal Interaction

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Abstract: This paper discusses the background and basis behind a computer program developed by the author that incorporates a haptic feedback and audio interface into a visually interactive simulation of the structural response of buildings to fire. Structures are limited to steel in particular. The audio interface makes use of sonification and affective techniques while the haptic interface takes advantage of force feedback technology. The simulation is also meant to be holistic, qualitative, intuitive, temporal yet interactive. The primary innovation in this fire simulation system is the incorporation of audio and haptic feedback interaction into the usual visual interface.

1 INTRODUCTION

It is vital for students of architecture and engineering to acquire a firm understanding and appreciation of the structural response of buildings to fire. One way this may be achieved is by providing a holistic and qualitative evaluation of this phenomenon as it unfolds in real or scaled time.

Current digital technology allows precise predictions for behaviour of complete structural frames during the occurrence of fires. This paper discusses a computer program developed by the author that incorporates a haptic and audio interface into visually interactive simulations of the structural response of buildings to fire. To achieve a reasonable degree of realism and simulation accuracy, temperature/time characteristics of natural fires can be specified and finite element analysis is used taking into account both geometric and material non-linear effects. The simulation in this system is essentially a process that allows the student to observe the behaviour of the structure as a fire develops through a building. This temporal framework provides the student with information beyond just the real failure time. It imparts valuable insight and understanding of the stages leading to structural failure as successive formation of plastic zones and local buckling eventually lead to a structural mechanism.

The interface is multimodal and apart from the usual visual stream, it consists of an audio and haptic stream as well (Figure 1). The audio interface imparts information related to changing temperature or structure "distress" through sonification and affective techniques. The haptic interface uses simple force feedback technology to also provide the user with cues on changes in temperature as well as intuitive way of monitoring the stiffness, strength and stability of the structure during the progress of the fire. The visual stream mainly depicts deformation, spread of plastic zones, and eventual progress towards collapse.

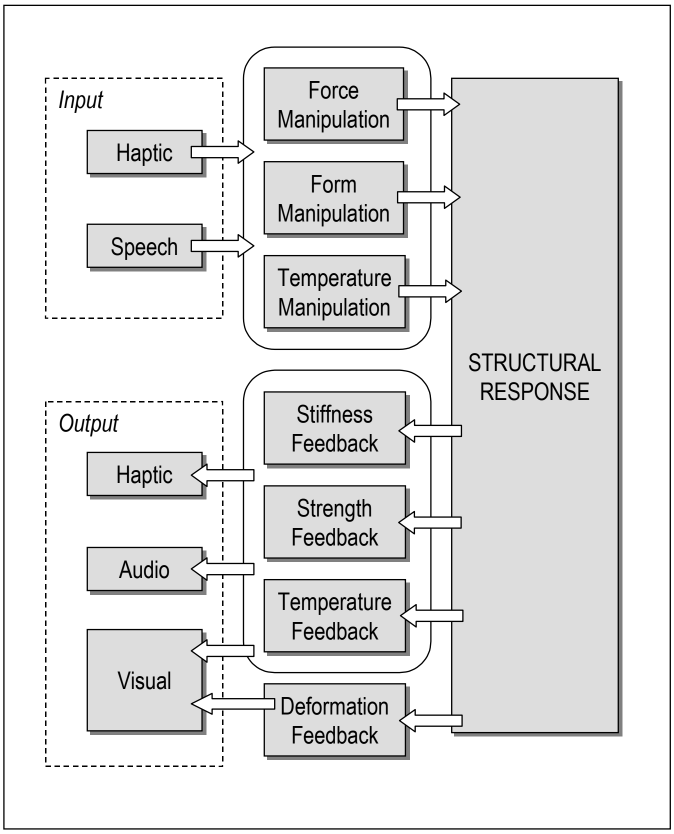

Figure 1 The Multimodal Interface

2 STRUCTURE ON FIRE

Audio, haptic and visual cues are integrated into the structural behaviour system developed for this project through simulated time-history response of structures to a real fire, or the life of a structure as I would like to call it. A simulated behaviour of a structure as fire leads to its collapse could be presented as a scaled temporal process wherein a structure undergoes initial and subsequently incrementally increasing temperatures until a collapse mechanism is attained. For complex redundant structures, behaviour through this process is non-linear mainly because of the onset and occurrence of phenomena which are a result of changing material properties, material plasticity, stress redistributions, sudden buckling, etc. It would provide students helpful insights into structural behaviour if they could observe this process as a structure 'lives' through its life (monitor its 'vital signs' so to speak) 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. 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. It is appropriate that the structural effects of fire on structures can be easily modelled globally (whole structures and not just elements) while considering changes in the mechanical properties of the materials (become weaker and more flexible) as well as resulting strains induced (expansion). Software of this nature has begun to evolve but typically use only the visual interface for output (Wong, Robinson and Buchanan 2001; Wang 2002).

The behaviour of steel frames in particular provides an interesting study for students. The advent of advance analysis in place of 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. Advanced analysis techniques are therefore an ideal basis for depicting the temporal process of simulated structural collapse.

3 MULTIMODAL PRESENTATION OF SIMULATION

As fire begins to develop in a structure, the gas temperature rises resulting in subsequent rise in temperature of the steel as well. Changes in the stiffness and strength of the steel ensue and thermal strain begins to develop. The structure undergoes second order inelastic effects and may at some point collapse. These various aspects of structural behaviour can be conveyed to the user of the system through the 3 main modalities of output: audio, haptic and visual. Figure 2 shows a summary of how gas or steel temperature changes can be sensed by the user through the 3 main output modalities. Figure 3 on the other hand shows a summary of how changes in stiffness, strength and deformation are conveyed.

3.1 Visual Channel

The visual display of the multimodal interface of this system shows several key aspects of structural response of the structure as fire develops and ultimately leads to

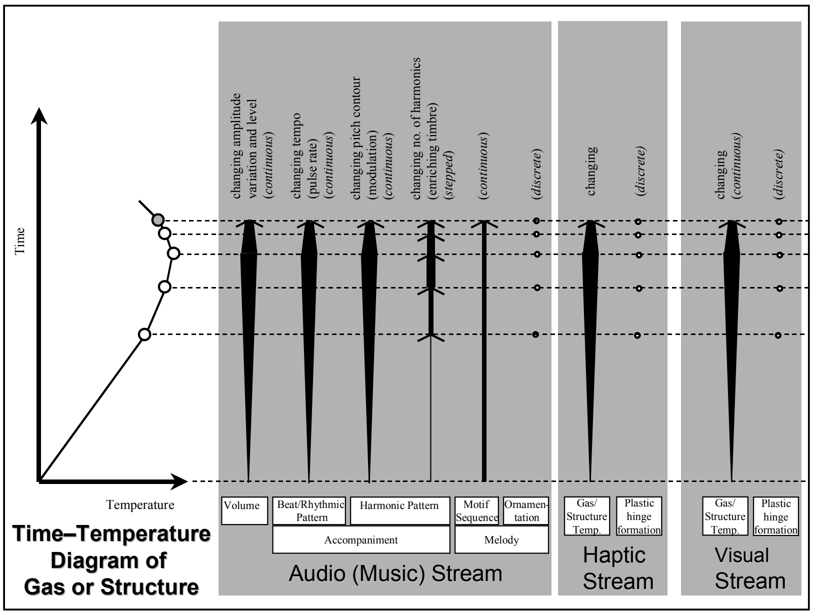

Figure 2 Audio, Haptic and Visual Output Conveying Changing Temperature

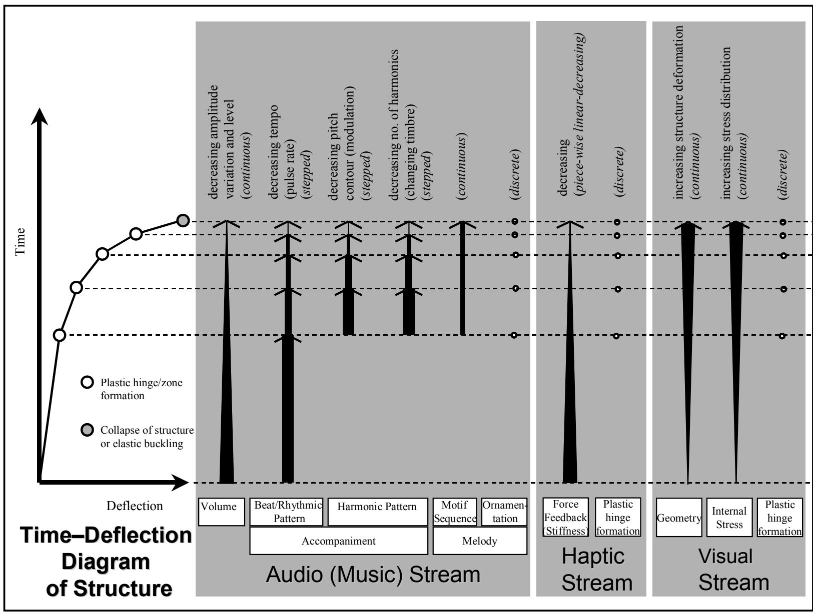

Figure 3 Audio, Haptic and Visual Output Conveying Stiffness/ Strength/ Deformation

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 Audio Channel

In the multimodal interface, audio is used in resonance with the graphical display for three main reasons. First is to impart changing parameters such as gas or steel temperature or changing steel properties such as stiffness, strength and stress. Second is to indicate the rate at which these changes occur. Third is to define segments or discontinuities in the structural behaviour.

3.2.1 Use of Basic Perceptual Properties of Sound

Several attributes of sound can be used to represent various structural data. These include pitch, loudness, timbre, tempo and vibrato.

Pitch typically refers to our perception of sound of a fundamental frequency and timbre. Its use provides an effective way of differentiating order. In using pitch however, it was necessary to keep within a perceptible range and interval. Sound frequencies in the interface needed to be within a range of 5 to 4000Hz as there is normally a breakdown in interval perception below 5Hz and also a breakdown in pitch judgments above 4000Hz (approximately the highest note on the piano). Also, individuals can normally, easily distinguish semi-tone intervals of chromatic scales over about 5 octaves. In effect the frequency bandwidth range as well as interval of the piano was used for representation.

Loudness is another sound attribute and is one that has a natural interaction with pitch. Loudness and pitch tend to enhance each other and can be used to represent the same data simultaneously in order to achieve a richer more compelling sonification. Mapping of a single data stream to multiple auditory variables may result in subjectively richer, stronger and more focused sounds (Kramer 1996).

Musical complexity or richness of a sound is commonly referred to as timbre. As to the use of either musical instrument timbres or simple tones, experiments have indicated that use of the former is more effective (Brewster 1994). Furthermore, the use of different musical instrument as well as natural sound timbres can be used to improve differentiation among sound streams. This also enables selection of timbres that are closely associated to the physical parameters they represent.

As real time simulation is vital to the program, sound attributes with a strong temporal dimension are essential. Tempo & vibrato are two such attributes that do have a strong temporal dimension. This makes them ideal in portraying the various time-varying data. Tempo refers to the rate at which discrete tones are played. Vibrato on the other hand is the slow flutter in the amplitude of a generally continuous sound.

3.2.2 Generation of the Affective Audio (Music) Stream

A flexible degree of interactive music generation is necessary in the system in order to seamlessly tie into the interactive structural behaviour simulations in real or scaled time. There has been greater development and use of interactive music systems in the past years mostly in keeping with advancements in multimodal/ multimedia technology. Methods and techniques for such systems have been and continue to be established (Rowe 1993; Matthews 1991; Nakamura1993). In the program, music is generated with parametrically filtered sequences. The short pre-composed segments are then varied along acoustic parameters like tempo, volume and timbre.

The tempo of the background music used in the structural simulations are based on that of a human heartbeat. These comprise of low frequency throbbing pulse beats. It would seem appropriate that the starting basic tempo be based on the pulse rate of a normal human being. 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).

A melody is generated and played to the tempo set by the beat. Predefined motif sequences generate the melody that is transformed according to chord progression selected from preset progressions.

Levels of tension and anxiety in the music can be manipulated through changes in harmony, rhythm patterns, and texture of the sound. Harmony and rhythm patterns are selected from an indexed database and provide the musical accompaniment. As for varying the texture of the sound, this is done by changing the number of musical instruments playing simultaneously.

Occasionally, significant structural events during the structural simulation need to be brought to the attention of the user when necessary. This is done through short musical ornamentations imparted at the onset of these events.

3.3 Haptic Channel

Several studies have begun to be made on the advantages of using force feedback in virtual environments. Some of these studies are in areas such as medical training, entertainment, telerobotics and the military (Burdea 1996). Studies and applications on force feedback dealing with the development of realistic force sensations in virtual environments as well as manipulation of simple deformable objects and surfaces have been undertaken (Thalmann 1995; Yokoi et al. 1994; Popa and Singh 1998).

Force feedback was incorporated into this application to provide stronger, more intuitive user-structure interaction. Figures 2 & 3 illustrate the role of haptic force feedback within the context of the multimodal interface. All three output modalities (haptic, visual and audio) are imparted simultaneously in parallel to achieve a greater bandwidth of conveyed information. The structural response information from the three modalities may be both complementary and/or redundant. The redundancy is intended to provide the user with greater sensitivity to the structure's behaviour as previous studies have shown that such redundancy provided by the haptic channel increases the effectiveness of the interface (Richard and Coiffet 1995; Fabiani and Burdea 1996).

The system makes use of relatively inexpensive force feedback joysticks and mice. These, being simple and intuitive devices, have been very popular in the past many years. Those with force feedback capabilities are now readily available and relatively inexpensive. The force feedback joystick and mouse used in this structural behaviour system is a simple 2-degree of freedom haptic device. This device is capable of 2-dimensional feedback forces on the horizontal plane. In dealing with the 3-dimensional virtual structures, it is necessary to define or select a transformation setting to enable the user to apply and receive forces within a desired plane.

4 SENSORY INTEGRATION

As all the sensory modalities (visual, auditory and haptic) are describing the same event and object, they must be synchronized in portraying the different parameters of structural states or behaviour through a periodic or transient time frame. A generally accepted rule states that the integrated representation of synchronized audio-visual objects (audio and video) becomes more enhanced when the complexity of information conveyed is higher, resulting in better extraction of information than from single senses (Stein and Meredith 1993). The large bandwidth and complexity of information of structural fire simulations makes it ideal for multimodal presentation.

4.1 Modalities Imparting Redundant and Complementary Information

The various relevant structural parameters can each be represented through either the visual, auditory or haptic channel. This blending of modalities makes it flexible enough to permit two methods of streaming of information through the interface. In the first method the 3 channels convey redundant or overlapping information. Here the information through one sensory modality reinforces the same information that passes through another. In the second method the visual, auditory and or haptic channel each impart different but complementary data. This results in a larger bandwidth of data conveyed. It also allows for important relationships among the different structural parameters to be observed.

4.2 Simulation Speed

It is sometimes desirable to arm the user with the capability of scaling the speed of the simulation. Depicting the structural response of structures to fire in the real time scale is not always necessary in most instances. Time scaling options are provided to enable students to slow down or speed up the simulations depending on their cognitive capacity. This flexibility in speed is acceptable so long as the streams of information emanating from all interface streams are synchronized.

4.3 Interactive Exploration

Because of the temporal dimension of the simulations, the intended interactive nature of the program is in a way somewhat compromised. Nevertheless, interactivity is still achieved through multiple windows each depicting incrementally varying structural/ environmental parameters. This can enable users to detect patterns of behaviour and relationships in a qualitative rather than quantitative manner.

5 SUMMARY

In summary, the system depicts the behaviour of a structure of a building on fire through a multimodal interface. The potentially large output bandwidth such a multimodal interface provides enables a more natural experience of structural behaviour processes resulting from events such as fire. The simulation is also meant to be holistic, qualitative, intuitive, temporal yet interactive and therefore not intended for precise quantitative structural design thereby making it inadequate in that regard. The primary innovation in this fire simulation system is the incorporation of audio and haptic feedback interaction into the usual visual interface.

Further investigations particularly on achieving improved sensory integration are planned.

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