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Extending Active Control to Build Intelligent Structures

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Summary

Intelligent structures react to changes in their environment (loads, movements, etc.) through *i)* measurement of structural behaviour, *ii)* evaluation using knowledge bases, *iii)* use of computational control to modify actively structural characteristics and *iv)* use of past events to improve structural performance. A computational framework based on intelligent control methodology is presented that combines reasoning from explicit knowledge, search, and learning to illustrate capabilities of intelligently controlled structures. Using this framework, a computational system and its application to tensegrity structures are under development. Such computational control systems are stimulating the design and construction of innovative structures, thereby extending design possibilities for structural engineers.

Keywords: Active control, intelligent structures, case-based reasoning, simulated annealing, tensegrity structures

1. Introduction

The potential for intelligent structures stems from a combination of advances in structural engineering, control engineering and artificial intelligence research. For structures that are governed by safety criteria, most active control systems will not be reliable enough over service lives without expensive system maintenance. Such extra costs are difficult to justify economically. When dominant design criteria do not involve catastrophic collapse or loss of life, active control is most practical. Active control of structures provides a means of continuously controlling performance of complex structural systems to ensure good performance in changing and uncertain environments. Use of artificial intelligence (AI) methodology has the potential to enhance the benefits of structural control. This paper begins with a discussion of potential applications and refines the definition of intelligent structures given in the summary. A computational framework is outlined in Section 3 and this has been applied to tensegrity structures in Section 4. This application employs a unique control system (Section 5) that is an instantiation of the computational framework.

2. Intelligent structures

The term "intelligent structures" has been used to describe structural engineering technologies ranging from structures with embedded active materials to structures with artificial neural network controllers. This paper introduces a refinement of the definition of intelligent structures in order to provide a focus on long-term performance-based control of civil structures. Intelligent structures have two attributes: at least one active feature, and a computational control system that performs functions such as : adaptation of structural geometry to improve performance; control objectives that arise from multiple, changing performance goals; autonomous and continuous control of multiple, coupled structural subsystems; reasoning from explicit and modifiable domain knowledge; improvement of structural performance over time (learning and planning).

3. Computational Framework

Details of the computational control methods are shown in Figure 1. Many combinations of reasoning, search and learning methods can be used within this framework.

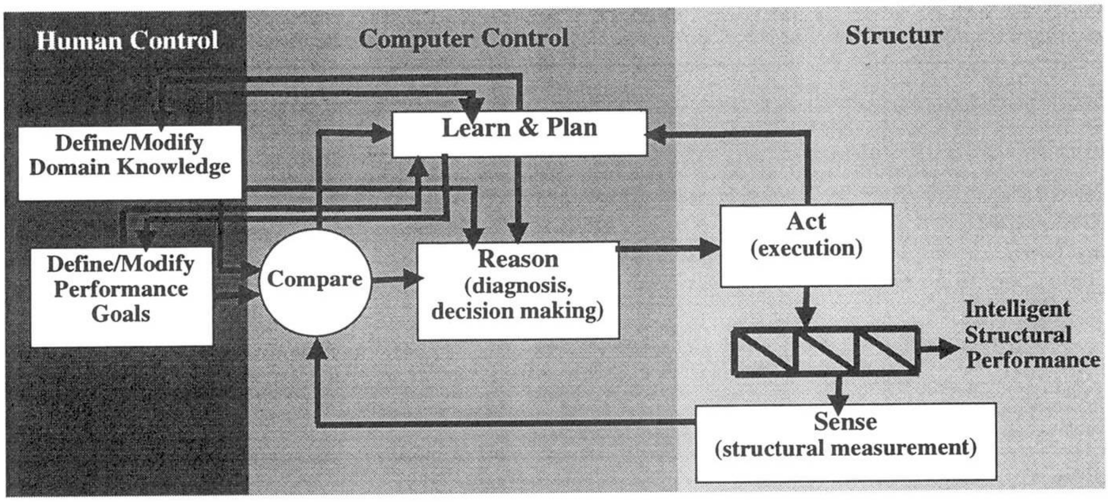

Fig. 1 Framework for intelligent computational control of complex structures.

4. Application to Tensegrity Structures

Tensegrity (tensile-integrity) structures are lightweight, reusable structures. Since tensegrity structures are sensitive to asymmetric loads and small changes in external loading, active control helps make them suitable for practical use. A system developed from the framework presented in Figure 1 is intended to control tensegrity roof structures such as those employed for exhibition at the Expo.01 in Switzerland in 2001. The design consists of coupled active features that require continuous control in order to maintain and improve system performance. A roof system is comprised of tensegrity (tensile-integrity) modules each of which consists of a self-stressing system of compression struts and tensile wires where the stress distribution and shape of the module is controlled by telescoping struts. The control problem is then to determine the lengths of active struts that best distribute the stress in the structural system in a changing environment while keeping the roof fabric in tension.

5. Computational Control System

For the tensegrity system described above, the initial behavioural objectives are shape control to maintain fabric tension and stress control to keep wires from going slack. Given a loading condition and corresponding structural deformations, the computational control system determines a set of movements of the active struts that will return the structure as close as possible to the initial shape. To achieve these structural control goals the current computational control system is comprised of three modules: (1) state evaluation, (2) simulated annealing search, and (3) case-based reasoning. Simulated annealing performs a global search of the combinatorial space of possible movements to produce control solutions. Since simulated annealing is a lengthy iterative process, a case-base of previous solutions acts as a means for speeding up reasoning and for enhancing solution quality through knowledge about past successes.

6. Conclusions

When serviceability requirements are important design criteria, continuous active control becomes justifiable. Intelligent structures are capable of interacting with complex environments and improving performance with time. Structural control systems which use explicit knowledge representation, search and learning, will create new possibilities for innovative, active structures.[1]