ABSTRACT

Feedback control systems are widely used to modify the dynamic behavior of the engineering systems. They require sensors to measure some aspects of the system response, signal processors to realize the control law and the actuators to affect the system. The sensors and actuators are usually very similar to instruments and amplifiers and thus are typically modeled using active bonds, using bond graph technique which, since they work on the principle of conservation of energy, it is difficult to accidentally introduce extra energy into a system.

Virtually any type of physical system (mechanical, electrical, electro-mechanical, hydraulic, etc.) can be modeled using the bond graph technique. Since each bond represents a bi-directional flow, systems which produce a “back force” on the input are easily modeled without introducing extra feedback loops.

Bond graphs are based on the principle of continuity of power. If the dynamics of the physical system to be modeled operate on widely varying time scales, fast continuous-time behaviors can be modeled as instantaneous phenomena by using a hybrid bond graph.

The signal processor which is usually a special purpose analog or digital computer, is not normally described by it’s action on certain signals without regard to any physical power required hence it is difficult to have bond graph of it as bond graphs are based on the principle of continuity of power.

For this purpose in this research paper we have applied a technique that can give composite representation in which the physical system is represented using bond graphs and the controller is represented as a signal processor. For simple systems the resulting combined system may yield insight but for more complex systems, the result may be too complicated to be of much use.

We have taken the example of an electronically controlled automotive suspension featuring a fast acting load leveler and a semi active damper and have successfully simulate the system by our mixed bond graph approach.

Key Words: Feedback Control System, Actuators, Composite Representation, Bond Graph Modeling.

1 INTRODUCTION

1.1 Feedback control systems

Feedback controls systems can be found in many different industries, including aerospace, automotive, chemical, power, and semiconductor manufacturing. A systems level understanding of dynamic behavior and feedback compensation will be extremely useful when specifying, modifying, or designing such systems.

1.2 Sensors and Actuators

They are also called: transducer, probe, gauge, detector, pick-up etc. A device that responds to a physical stimulus and transmits a resulting impulse or a device, such as a photoelectric cell, that receives and responds to a signal or stimulus or simply a device that responds to a physical stimulus (as heat, light, sound, pressure, magnetism, or a particular motion) and transmits a resulting impulse (as for measurement or operating a control). Where as an actuator is a device responsible for actuating a mechanical device such as one connected to a computer by a sensor link or the one that actuates; a mechanical device for moving or controlling something. Feedback control systems are widely used to modify the dynamic behavior of engineering systems. They require sensors to measure some aspects of the system response, signal processors to realize the control law, and actuators to affect the system. The sensors and actuators are usually very similar to instruments and amplifiers and thus are typically modeled using active bonds. The signal processor, which is usually a special purpose analog or digital computer, is normally described
by its action on certain signals without regard to any physical power required.
Naturally, a sensor or an actuator is really a physical system and could be described by a bond graph. For a well designed system this is neither necessary nor desirable, and it is common practice to use signal flow graphs, block diagrams, or computer programs to describe the information processing which goes on between the sensor output and the actuator input in a controlled system. When the sensors or actuators have dynamics which cannot be neglected, they can be incorporated either as part of the physical system or, more artificially, as part of the dynamic laws of the control system itself.

2 MODELING OF PHYSICAL SYSTEMS BY BOND GRAPH

2.1 Physical systems may be regarded as energy manipulating units and modeling them is based on the distribution and transfer of energy taking place within them. Energy from certain sources enters a system schematically as shown in Figure 1 and is manipulated within the system by the various components and subsystems in accordance with their inherent properties and depending on the manner in which they are connected inside the system. Energy manipulation phenomena are studied in terms of a pair of variables whose product has the sense of power and thereby the meaning of energy. Some elements store energy and some convert it onto another form. When an element converts energy into heat, it is termed as a dissipator.

The energy manipulations in system elements are studied in terms of 'effort variables' and 'flow variables' whose product corresponds to the 'rate of energy' or 'power' as indicated in Figure 2 in general. For instance, in an electrical system shown in Figure 3, voltage is regarded as an effort variable and current as the flow variable. Because of the manner in which the effort and flow variables occur, for instance, as voltage across an element and current through it, they are also termed as 'across' and 'through' variables respectively. [2]

![Fig.2: Effort and flow variables](image)

The elements within a given system may have the property to store or dissipate energy. Energy stores are classified as effort stores and flow stores. For example, in electrical systems, inductors accumulate the effort variable (voltage) and capacitors accumulate the flow variable (electric current). Resistors convert electrical energy into heat and are termed as dissipators.

Graph theoretic methods may be applied as general tools to apply the interconnectivity constraints. These constraints will eliminate the redundancy in the labels chosen to describe the variables. Furthermore, it is enough if all but one of the effort variables in the loop are labeled. The unlabeled variable is naturally determined by the negative sum of these n-1 variables. Thus application of the interconnectivity constraints brings down the multitude of the system variables to the appropriate number and mutual relationships. The resulting equations are then arranged in the desired form to represent the system model.[4]
3.1 Composite Representation for Controlled Systems

For controlled systems, then, it is advantageous to use composite representations in which the physical system is represented using bond graphs and the controller is represented as a signal processor. We illustrate the choices of representation through an example. The signal processing will be represented through the use of block diagrams of various degrees of specificity. The combination of bond graphs and block diagrams is particularly useful when a continuous system simulation program which can accept bond-graph models directly is available. In such a program the bond-graph equations are generated automatically and the block diagrams or control algorithm only need to be added. Alternatively one could represent even the bond-graph is nothing more than a very compact representation of the information in a block diagram or equation set. For simple systems, the resulting combined block diagram may yield insight, but for more complex systems, the result may be too complicated to be of much use.\[6\]

3.2 Example for Composite Representation-

For finding out the composite representation a electronically controlled automotive suspension featuring a fast-acting load leveler and semi-active damper is selected as shown below in fig 5. For simplicity, the system shown is only a "quarter car" model with the mass \(M\) representing the body and \(m\) the wheel. The velocity \(V_o\) represents vertical velocity inputs from roadway unevenness, and \(k\) is a liberalized tire spring constant. A sensor is supposed to generate an approximation to \(V\), the absolute vertical velocity of the car body, and another measures \(X\), the wheel-to-body deflection.\[10\]
Figure 7: Block diagram of given system, simplified and rearranged into typical feedback controlled form.
The controller drives one actuator which provides the relative velocity \( V_c \) of the main suspension spring attachment point as a conventional load leveler does. The other controller output is \( F_c \) a command force which is to be realized by a semi-active damper. The damper is a variable resistor—for example, a hydraulic shock absorber with electromechanical valves. Obviously such a device cannot provide an arbitrary \( F_c \) since its force times its relative velocity \( X \) must always represent power dissipation. Thus in the model, a nonlinear function \( \Phi \) will be used to relate the actual damper force to \( F_c \) and \( X \). The details of \( \Phi \) depend on the philosophy of the particular semi-active damper law and the physical construction of the device.\[10\]

The \( 1/s \) block merely indicates that the \( X \)-signal on the active bond in integrated to obtain \( X \). (The symbol \( s \) represents the Laplace transform generalised frequency variable, so \( 1/s \) is the transfer function of an integrator.) This is an instance in which an active bond is treated exactly as a block diagram signal. The controller has a command input \( X_c(t) \) which is related to the desired ride height and could come from another supervisory controller. The controller output \( V_c \) drives an ideal velocity source. Actuator dynamics could be included if desired by replacing the ideal source with a physical model of the actuator—perhaps a voltage source acting on a model of an electric motor and gearbox. Alternatively some lag or delay might be incorporated in controller block diagram or algorithm to model the actuator dynamics more accurately. The signal \( F_c \) modulates the \( R \)-elements representing the controlled shock absorber. Again, engineering judgement is required to decide whether or not actuator dynamics in the semi-active damper should be included.

To simulate the system of Figure 6, one would only need to represent the bond graph without active bonds to a bond-graph processor and then add to the program the relationships relating \( F_c \) and \( V_c \) to \( V \), \( X \) and \( X \) from a control law such as the one shown in Figure 5. In fact, for that rather simple control law, an explicit bond-graph block diagram can be shown. See Fig 4 of Appendix. In combined diagram, virtually all relationships are clear except for the semi-active damper. Here only the command force to the damper is shown, but what the actual force will be must still be specified.

Since the bond graph of Fig 4 of Appendix, is equivalent to a block diagram, it is possible to convert to a complete block-diagram representation. As shown in Figure 8 this results in a very explicit but complex representation because all of the internal efforts and flows are shown. Despite some theoretical advantages to such a block diagram, few control engineers would be enthusiastic over it.

By combining some linear operations and rearranging the diagram of Fig 5 of Appendix, diagram more to the liking of control engineers can be developed. It is shown in Figure 7, Here the command \( X_c \), response \( X \), and disturbances \( F_0 \) and \( V_0 \) are shown together with feedback loops from \( V \) and \( X \) in a conventional layout. Certainly such a diagram helps one to understand the control aspects of the system. However, the distribution between finite-power and zero-power signals has been lost completely.\[10\]

**RESULTS AND CONCLUSION**

In this research paper we have applied a technique that can give composite representation in which the physical system is represented using bond graphs and the controller is represented as a signal processor. For simple systems the resulting combined system may yield insight but for more complex systems, the result may be too complicated to be of much use.

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