DECENTRALIZED CONTROL OF LARGE-SCALE SYSTEMS

Younes Alfitorey Mousa[1]
Department of Cybernetics and Artifical Intelligence
Faculty of Electrical Engineering and Informatics
Technical University of Kosice
Slovak Republic: akaks2@yahoo.com

This paper consists in an overview of the large-scale systems and methods of decentralized control, which ensures the dynamic properties of the individual subsystems. Study the effect of interaction with some change in parameter.

Keywords: large-scale systems decentralized control, hierarchical system, hierarchical control of large-scale systems, discrete events.

1. INTRODUCTION

The notion of *"large-scale"* is a very subjective one in that one may ask: How large is *large?* There has been no accepted definition for what constitutes a "large-scale system." Many viewpoints have been presented on this work. One viewpoint has been that a system considered *large-scale* if it can be decoupled or partitioned into a number of interconnected subsystem or "small-scale" systems for either computational or practical reasons. Another viewpoint is that a system is *large-scale* when its dimensions are so large that conventional techniques of modeling, analysis, control, design, and computation fail to give reasonable solutions with reasonable computational efforts. In other words, a system is large when it requires more than one controller. [4] Since the early 1950s, when classical control theory was being established, engineers have devised several procedures, both within the classical and modern control contexts, which analyze or design a given system. procedures can These be summarized as follows:

- Modeling procedures, which consist of differential equations, input-output transfer functions, and state-space formulations
- Behavioral procedures of systems such as controllability, observability, and stability tests, and application of such criteria as Routh- Hurwitz, Nyquist, Lyapunov's second method.
- Control procedures such as series compensation, pole placement, optimal control, etc.

The underlying assumption for all such control and system procedures has been "centrality" (Sandell et al.1978), i.e. all the calculations based upon system information (be it a priori or sensor information) and the

information itself are localized at a given center, very often a geographical position. A notable characteristic of most *large-scale systems* is that centrality fails to hold due to either the lack of centralized computing capability or centralized information. Needless to say, many real problems are considered large-scale systems are that they often model real-life systems and that their

Large-scale, high performance systems often cannot be controlled (whether in direct or supervisory mode) by a single individual; the man-machine paradigm of a single human operator in the loop is not adequate for this case. Furthermore, classical *organization theory* also dose not meet the need for designing the organizational structure or architecture of a team supported by complex *decision support systems*. The design of air traffic control centers, energy control centers, the tactical command center of a military organization, or the higher level control of intelligent machines are applications where the design of the control systems cannot be decoupled from the design of the decision-making architecture. To control large, complex systems engineers are usually forced to use a combination of continuous and discrete controllers [10]. Continuous controllers are particularly useful as the interaction with the physical plant (through sensors and actuators) is essentially continuous. More over, continuous models and powerful continuous control techniques have been developed and validated extensively in the past. On the other hand, discrete abstractions help to manage the complexity of the system, are convenient to compute with, and make it easier to introduce linguistic and qualitative information in the design process. Systems that incorporate both continuous and discrete dynamics are typically referred to as hybrid systems.

2. HIERARCHICAL CONTROL OF LARGE-SCALE SYSTEMS

The notion of large-scale system, as it was briefly discussed, may be described as a complex system composed of a number of constituents or smaller subsystems serving particular functions and shared resources and governed by interrelated goals and constraints (Mahmoud, 1977). Although interaction among subsystems can take on many forms, one of the most common one is hierarchical, which appears somewhat natural in economic, management, organizational, and complex industrial systems such as steel, oil, and paper. Within this hierarchical structure, the subsystems are positioned on levels with different degrees of hierarchy. A subsystem at a given level controls or 'coordinates' the units on the level below it and is in turn, controlled or coordinated by the unit on the level immediately above it. Figure. (1). shows a typical hierarchical ("multilevel") system [4]. The highest-level coordinator, sometimes called the *supremal coordinator*, can be thought of as the board of directors of a corporation, while another level'scoordinators may be the president, vice-presidents, directors, etc. The lower level can be occupied by plant managers, shop managers, etc, while

3. DECENTRALIZED CONTROL

Most large-scale-systems are characterized by a great multiplicity of measured outputs and inputs. For example, an electric power system has several control substations, each being responsible for the operation of portion of the overall system. This situation arising in a control system design is often referred to as *decentralization.* The designer for such systems determines a structure for control, which assigns system inputs to a given set of local controller (station), which observe only local system output. In other words, this approach, called *decentralized control*, attempts to avoid difficulties in data gathering, storage requirements, computer program debugging, and geographical.

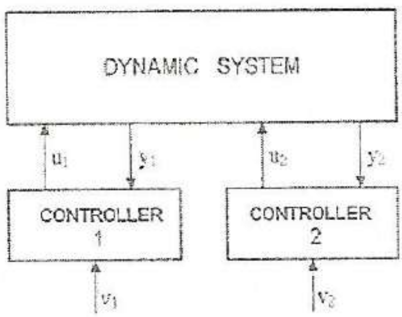


Fig2. Decentralized control structure.

The basic characteristic of any decentralized system is that from one group of sensors or transfer of information actuators to others is quite restricted. For example, in the system of figure (2) only the output y_1 and external input v_1 are used to find the control u_1, and likewise the control u_2, is obtained through only the output y_2

and external input v_2. The determination of control signal u_1 and u_2 based on the output signals y_1 and y_2, respectively, is nothing but two independent output feedback problems, which can be used for stabilization or pole placement purposes. It is therefore clear that the decentralized control scheme is o

f feedback from, indicating that this method is very useful for large-scale linear systems

This is a clear distinction from the hierarchical control scheme, which was mainly intended to be an open –loop structure.

$$u_{i,k} = -R_i^{-1} B_{i,k}^T K_{i,k} x_{i,k} + R_i^{-1} B_{i,k}^T h_{i,k} \qquad (5)$$

where r(t) = k ; i = 1,2,..., N; k = 1,2,.. .,s. The matrices $K_{i,k}$ and the vectors $h_{i,k}$ can be computed from a set of coupled stochastic differential equations:

$$\dot{K}_{i,k} = -A_{i,k}^T K_{i,k} - K_{i,k} A_{i,k} + + K_{i,k} B_{i,k} R_i^{-1} B_{i,k}^T K_{i,k} - Q_i - \sum_{l=1}^{s} p_{k,l} K_{i,l} \qquad (6)$$

$$K_{i,k}(T) = 0$$

$$\dot{h}_{i,k} = -\left[A_{i,k} - B_{i,k} R_i^{-1} B_{i,k}^T K_{i,k}\right]^T h_{i,k} + + K_{i,k} \sum_{\substack{j=1 \\ j \neq i}}^{N} A_{i,k} x_j + \sum_{\substack{j=1 \\ j \neq i}}^{N} A_{ji,k}^T (K_{j,k} x_j - h_{j,k}) - - \sum_{l=1}^{s} p_{k,l} h_{i,l} \qquad (7)$$

$h_{i,k}(T) = 0; \quad i, j = 1,2,\ldots,N; \quad k,l = 1,2,\ldots,s$

The equation (6) is generally known from [8], [9]the equation (7) is obtained from the equations for deterministic problem where is necessary to compute M $\{h_{i,k}(t)\}$ = M $\{h_{i,k}(t) | \, r(t) = k\}$ the proof of the relation (7) is described in [6]..

hierarchical (multilevel) and decentralized structures depict systems dealing with society, business, management, the economy, the environment, energy, data networks, power networks, space structures, transportation, aerospace, water resources, ecology, and flexible manufacturing networks, to name a few. These systems are often separated geographically, and their treatment requires consideration of not only economic costs, as is common in centralized systems, but also such important issues as reliability of communication links, value of information, etc. If is for the decentralized and hierarchical control properties and potential application that many researchers throughout the world have devoted a great deal of effort to large-scale systems in recent years. Similar problems exist as well in other complex systems, such as in command and control systems, computer networks; complex aircraft control systems, and chemical process and power systems and distribution and highway, among others. These continuous efforts systematically from a body of *large-scale systems* theories, which deals with several aspects of complex systems. These *large-scale systems* consist of many subsystems, which have access to different information and are making their own local decisions, but must work together for the achievement of a common, system-wide goal [7]. Each subsystem often possesses limited prior knowledge of the details of the overall organization its model often describes only the subsystem itself and portions of other subsystems strongly coupled with the former consequently, each subsystem may be operating with limited Knowledge on the structure of the remainder of the system which may be reconfiguring itself dynamically due to changing requirements, changes in the environment, or failure of components. The representation of such prior knowledge in a modular way to provide a consistent interface between different subsystems is challenging unsolved problem. Each subsystem has its own sensors collecting data and local processors generating information, which must be integrated with the information obtained by other subsystems to be used for decision-making

the large-scale system is the corporation itself. In spite of this seemingly natural representation of a hierarchical structure, its exact behavior has not been well understood mainly due to the fact that very little quantitative work has been done on these large-scale systems (March and Simon, 1958) Mesarovic et al.(1970) presented one of the earliest formal quantitative treatments of hierarchical (multilevel) system. Since then, a great deal of work has been done in the field (Schoffler, and Lasdon, 1966; Beneveniste et al, 1976; Smith and Sage,1973; Geoffrion,1970; Schoffler, 1971; Pearson, 1971; Cohen and Jolland, 1976; Sandell et al, 1978; Singh, 1980).

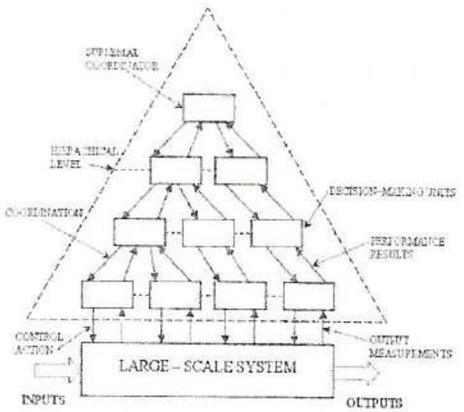


Fig1. A hierarchical (multilevel) control strategy for a large-scale system

For a relatively exhaustive survey on the multilevel systems control and applications, the interested reader may see the work of Mahmoud (1977). In this section, a further interpretation and insight of the notion of hierarchy, the properties and types of hierarchical processes, and some reasons, for their existence are given. There is no uniquely or universally accepted set of properties associated with the hierarchical system. However, the following are some of the key properties

- A hierarchical system consists of decision-making components structured in a pyramid shape figure. (1).
- The system has an overall goal, which may (or may not) be in harmony with all its Individual components.
- The various level of hierarchy in the system exchange information (usually vertically) among themselves iteratively.
- As the level of hierarchy goes up, the time horizon increases; i.e, the lower-level components are faster than the higher-level ones.

4. DECENTRALIZED CONTROL WITH DISCRETE EVENT

It will be assumed that the large-scale system to be controlled is described by the linear vector differential equations:

$$\dot{x}_i = A_i[r(t)]x_i + B[r(t)]u_i + \sum_{\substack{j=1 \\ j\neq i}}^{N} A_{ij}[r(t)]x_j \qquad (1)$$

where $x_1(t) \in R^n$ is the system state, $x_1(t) \in R^m$ is the control and A_i, B_i, A_{ij} are matrices of dimensions n x n, n x m, n x n, respectively. The stochastic behaviour comes from the dependence of A_i, B_i, A_{ij} on r(t). Denote the event $[A_i(t), B_i(t), A_{ij}(t)] = [A_{i,k}, B_{i,k}, A_{ij,k}]$ when r(t) = k and denote the set S = {1,2,..., s}. The stochastic variation of the process parameter will be described by the Markov Process r(t):

$$\Pr\{(t+\Delta)=l \mid r(t)=k\} = \begin{Bmatrix} p_{kl}\Delta + o(\Delta), k\neq 1 \\ 1+p_{kl}\Delta + o(\Delta), k=1 \end{Bmatrix} \qquad (2)$$

$$p[r(t_0)=k] = p_k; \qquad k-1,2,\ldots\ldots,s; \; k,l \in S$$

Here $P = [p_{kl}]$ is (s x s) matrix with $p_{kl} \geq 0$, $k \neq 1$,

$$p_{kk} = -\sum_{\substack{l=1 \\ l\neq k}}^{s} p_{kl}$$

Denoting the state probability vector as;

$$p(t) = [p_1(t), \ldots\ldots\ldots, p_s(t)]^T$$

and the transition matrix as P we can consider modes of the system as states of the Markov process with a finite number of states E_k, k = 1,2,..., s and continuous time:

$$\dot{p}(t) = P\,p(t); \qquad p(t_0) = p_0 \qquad (3)$$

It is assumed that the following sequence of events occurs at time "t":

1. x_i and x_j are observed exactly,
2. then $A_{i,k}$, $B_{i,k}$, $A_{ij,k}$ switches to $A_{i,l}$, $B_{i,l}$, $A_{ij,l}$,
3. then $u_{i,k}$ is applied in the sense of some averaged quadratic performance index

$$J = \sum_{i=1}^{N} J_i = \sum_{i=1}^{N} E\left\{\frac{1}{2}\int_0^T (x_i^T Q_i x_i + u_i^T R_i u_i)dt\right\} \qquad (4)$$

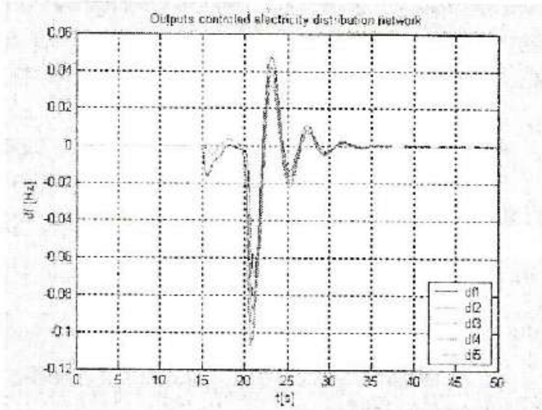
The optimal solution in the sense of (4) can be expressed

5. SIMULATION RESULTS FOR FIVE AREA SYSTEMS (with & without Interaction)

At the end of simulation is shown some interpretations of simulation, which are acquired from the simulation program *Matlab:*

5.1 Case (A):

Step Input (Pd) from 0 to 0.05.
Size (Pd1) = 0.01.
Size (Pd2) = 0.02.
Size (Pd3) = 0.03.
Size (Pd4) = 0.04.
Size (Pd5) = 0.05
Start of error time (Td1) = 20 (s),
Start of error time (Td2) = 20 (s).
Start of error time (Td3) = 20 (s)
Start of error time (Td4) = 20 (s).
Start of error time (Td5) = 20 (s).



.Fig.4 with Interaction

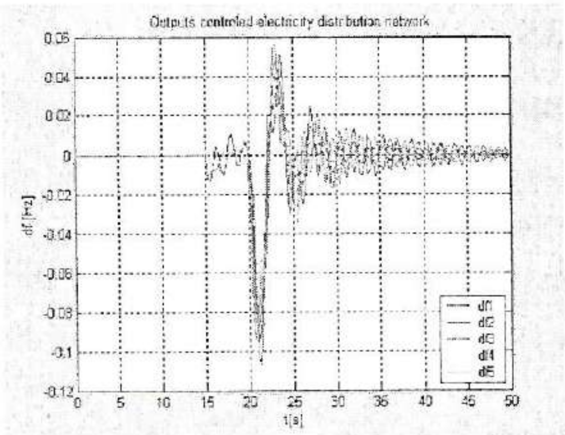


Fig.5 without Interaction

6. CONCLUSION

Large-scale systems are often controlled by more than one controller or decision maker involving "decentralized" computations. Large-scale systems can also be controlled by local controllers at one level whose control actions are being coordinated at another level in a "hierarchical" (multilevel) structure. Large-scale systems are usually represented by imprecise "aggregate" models. Controllers may operate in a group as a "team" or in a "conflicting" manner with single- or multiple-objective or even conflicting-objective functions. Large-scale systems can also be controlled by local controllers at one level whose control actions are being coordinated at another level in a "hierarchical" (multilevel) structure. Large-scale systems are usually represented by imprecise "aggregate" models. We observe that, from all results of five area systems the values of outputs decays till zero value and that when the control area systems is connected with the Interaction.

REFERENCES

[1]. Sarnovský J., Theory optimal and adaptive Systems, Rectorate TU, Košice, 1991.

[2]. Sarnovský J., Control of composite systems, ALFA Bratislava, 1988.

[3]. Sarnovský J., Madarász L., Bizík J., Csontó J., Control of composite systems, ALFA Bratislava, 1992.

[4]. Jamshidi M, Large-Scale Systems. Modeling and Control.

[5]. Baisová Z., Decentralized hybrid control of composite systems, Script toward academic Dissertation examination, 1998.

[6]. Sarnovský J., Reliable Decentralized Control System with Discrete Events, Bulletin for Applied Mathematics, TU Budapest, October 1991, pp.179.186.

[7]. Challenges to control: a collective view. Report of the Workshop Held at the University of Santa Clara On September 18-19, 1986.

[8]. David D. Sworder. Feedback control class of liner Systems with jump parameters..

[9]. Birdwell,J.D. ATHANS,M: On Reliable Control System Design. IEEE Trans. SMC, Vol. AC-16 October 1988,pp.703-711

[10]. John Lygeros, Datta N Godbole and S. Shankar Sastry Multivalent Hybrid System Design using Game Theory and Optimal Control.