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TOWARDS AUTONOMOUS CONTROL SYSTEMS

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Abstract

Control systems with high degree of autonomy should perform well under significant uncertainties in the system and environment for extended periods of time, and they must be able to compensate for certain system failures without external intervention. Such highly autonomous control systems evolve from conventional control systems by adding intelligent components, and their development requires interdisciplinary research. Note that it is possible to significantly increase the autonomy of a control system without necessarily adding intelligent components, although to obtain highly autonomous systems methods considered intelligent must be added. It should be stressed that from our point of view autonomy is the objective, and intelligent controllers are one way to achieve it.

After an introduction to the main ideas in Intelligent Autonomous Control Systems, a brief overview of this research area is given and certain important issues in modeling, analysis and design are discussed. Concepts and methods from Computer Science, Artificial Intelligence and Operations Research can and are being currently used quite successfully, together with methods from Control Systems, to address some of the problems. There are however additional problems in Intelligent Autonomous Control Systems of rather unique character, mainly pertaining to the real-time requirements, the dynamic characteristics of the systems involved and the need for a concrete theoretical framework to study important control properties of such systems; these problems require special consideration and need rather new concepts and methods and the researches into these problems are mostly at early stages. An outline of some of our recent work in Intelligent Autonomous Control Systems is presented, with emphasis on the use of Neural Networks in Control and on Hybrid Systems modeling, analysis and design.

Intelligent Control for High Autonomy Systems

There are cases where we need to significantly increase the operating range of control systems. We must be able to deal effectively with significant uncertainties in models of increasingly complex dynamical systems in addition to increasing the validity range of our control methods. We need to cope with significant unmodelled and unanticipated changes in the plant, in the environment and in the control objectives. This will involve the use of intelligent decision making processes to generate control actions so that certain performance level is maintained even though there are drastic changes in the operating conditions. It is useful to keep in mind an example which I call the Houston control example . It is an example that sets goals for the future and it also teaches humility as it indicates how difficult demanding and complex autonomous systems can be. Currently, if there is a problem on the space shuttle, the problem is addressed by the large number of engineers working in Houston Control, the ground station. When the problem is solved the specific detailed instructions about how to deal with the problem are sent to the shuttle. Imagine the time when we will need the tools and expertize particular problem ares of all Houston Control engineers aboard the space shuttle, space vehicle, for extended space travel.

In view of the above it is quite clear that in the control of systems there are requirements today that cannot be successfully addressed with the existing conventional control theory. They mainly pertain to the area of uncertainty, present because of poor models due to lack of knowledge, or due to high level models used to avoid excessive computational complexity. Heuristic methods may be needed to tune the parameters of an adaptive control law. New control laws to perform novel control functions should be designed while the system is in operation. Learning from past experience and planning control actions may be necessary. Failure detection and identification is needed. These functions have been performed in the past by human operators. To increase the speed of response, to relieve the pilot from mundane tasks, to protect operators from hazards, autonomy is desired. It should be pointed out that several functions proposed in later sections, to be part of the high autonomy control system, have been performed in the past by separate systems; examples include fault trees in chemical process control for failure diagnosis and hazard analysis, and control system design via expert systems.

The design process emphasized here is a bottom-up approach. One turns to more sophisticated controllers only if simpler ones cannot meet the required objectives. The need to use intelligent autonomous control stems from the need for an increased level of autonomous decision making abilities in achieving complex control tasks.

An Intelligent High Autonomy Control System Architecture For Future Space Vehicles

To illustrate the concepts and ideas involved and to provide a more concrete framework to discuss the issues, a hierarchical functional architecture of an intelligent controller that is used to attain high degrees of autonomy in future space vehicles is briefly outlined; full details can be found in [2]. This hierarchical architecture has three levels, the Execution Level, the Coordination Level, and the Management and Organization Level. The architecture exhibits certain characteristics, which have been shown in the literature to be necessary and desirable in autonomous systems. Based on this architecture we identify the important fundamental issues and concepts that are needed for an autonomous control theory.

Research Areas

A number of research areas important to intelligent autonomous systems will be identified.

We shall discuss some research results in the areas of Hybrid Systems, in Restructurable Control and FDI and in Neural Networks in Control Systems. To further stress the importance of mathematical modeling and methods and provide an introduction for the discussion of hybrid systems some concepts and approaches of quantitative modeling will also be presented

It is important to note that in order to obtain a high degree of autonomy it is absolutely necessary to, in some way, adapt or learn; in [7] it is shown how an expert learning system can be used to tune the parameters of an adaptive controller for a large flexible space antenna so to optimize its performance and then also enhance the operating range of the system by storing this information for future use. Neural networks offer methodologies to perform learning functions in the intelligent autonomous controller. In general, there are potential applications of neural networks at all levels of hierarchical intelligent controllers that provide higher degrees of autonomy to systems. Neural networks are useful at the lowest Execution level - where the conventional control algorithms are implemented via hardware and software - through the Coordination level, to the highest Organizational level, where decisions are being made based on possibly uncertain and/or incomplete information. One may point out that at the Execution level - conventional control level - neural network properties such the ability for function approximation and the potential for parallel implementation appear to be very important. In contrast, at higher levels abilities such as pattern classification and the ability to store information in a, say, associative memory appear to be of significant interest ; see discussion below and [8]. Learning is of course important at all levels.

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