Orbital Research Inc.

LINEAR ADAPTIVE CONTROL

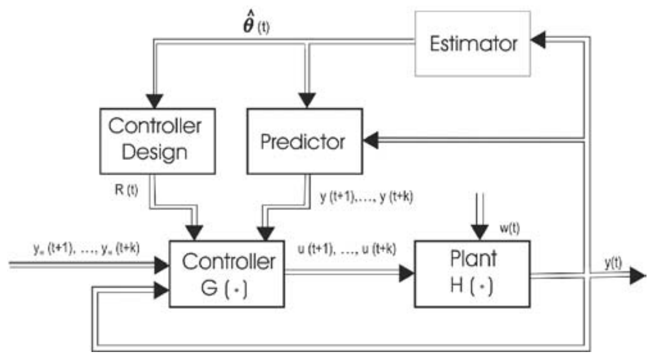
Flexible and robust control enabling today's applications

In an increasingly competitive market place, today's systems require a high degree of flexibility, robustness and performance. The need for ever faster, cheaper, and more capable systems is driving a concomitant requirement for more robust, capable and flexible control systems. One important class of modern control design techniques in this drive for better controllers is linear adaptive control. In an adaptive controller, the controller itself can adapt its behavior to accommodate changes in the system or the environment. Orbital Research, Inc. has developed a family of linear adaptive controllers for a variety of applications, including a computationally efficient predictive adaptive controller

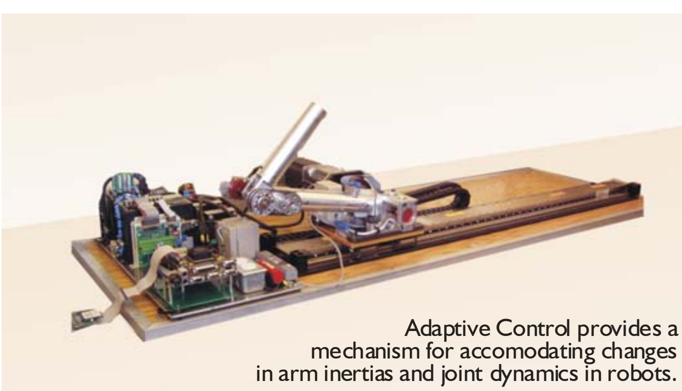
The Need for Adaptive Control

Occam's Razor dictates that the simplest control algorithm that will produce the desired results should be used and, hence, suggests the use of more conventional control theory that deals predominantly with linear, constant coefficient systems. Linear systems theory often provides a good approximation for systems being regulated about a fixed operating point. Unfortunately, linear control theory is not always sufficient, particularly in the presence of large variations in system parameters or disturbances. In addition, it not always possible to characterize a system sufficiently to permit the complete design of a suitable control system. The main reasons for using a nonlinear approach such as adaptive control are: 1.) variations in plant dynamics, 2.) variations in the characteristics of the disturbances, and 3.) engineering efficiency.

Many systems are inherently nonlinear and linear approximations are valid over only small regions of the systems operating envelope. For instance, a robot arm's inertial properties change nonlinearly with the arm's joint angles. Similarly, the performance of actuators can vary widely under different operating conditions such as changing temperature as well as degrade over time due to wear or other environmental effects. The use of an adaptive control scheme can greatly ameliorate the deleterious effects that changing system parameters have on the performance of the controller. While other techniques such as robust high gain control can often accommodate a wide range of system parameters, they do so at the cost of system performance. Only adaptive control techniques permit parameter variation while still allowing good control sensitivity and responsiveness.



Block diagram for the ORICA adaptve controller


Adaptive Control provides a mechanism for accomodating changes in arm inertias and joint dynamics in robots.

Disturbance accommodation is another important aspect of control design. It is a straightforward process to compensate for disturbances with given characteristics but the problem is far more difficult if the disturbance patterns are unknown or are **nonstationary**, or changing with time. A classical example of a nonstationary disturbance is wind load. As the weather conditions change, not only does the magnitude and direction of the wind change but the spectrum describing the wind load also changes, both in mode and shape. A constant gain controller designed to reject wind disturbances for a particular weather condition is not going to be nearly as effective in other weather conditions. Adaption provides a mechanism for retuning the disturbance rejection properties of the control system in response to changing environmental disturbances.

Finally, in many situations, the use of adaptive control is the simplest choice. In many applications, due to system complexity or inherent nonlinearity, it is either very difficult or impossible to deduce appropriate system parameters from first principals. It can therefore be advantageous to trade a more capable controller design against the potentially more effort consuming path of modeling, design and implementation of multiple control systems.

Orbital Research, Inc.
4415 Euclid Ave.
Cleveland, OH 44103

Contact: Frederick J. Lisy, Ph.D.
Telephone (216) 649-0399
E-mail lisy@orbitalresearch.com

www.orbitalresearch.com

Rev D RMK 12.2.2003

Orbital Research Inc.

Adaptive Control for Linearly Parameterized Systems

In linear adaptive control algorithms, a control law is designed based upon an assumed linear model. During operation, the parameters of this linear model are updated and the corresponding control design is adapted to reflect the updated model. Several different approaches exist for the updating of parameters, each based upon slightly different assumptions. One approach is to treat the problem as if the parameters are constant but unknown. This is known as the **tuning** problem and is the underlying assumption of **Self Tuning Regulators (STR)**, and related control algorithms. Typically, an identification algorithm such as least squares estimation is used to identify the unknown parameters. The **Certainty Equivalence Principle**, which holds that the identified parameters can be used as if they are equal to the true parameters, is invoked and the identified parameters are used to compute updated controller parameters via an automated design process. Another approach makes the assumption that the parameters are changing, though much more slowly than the state variables. The rate at which the parameters evolve in time can be controlled by the designer's choice of adaption rate. **Model Reference Adaptive Controllers (MRAC)** and their variants use this approach.

As noted above, adaptive controllers involve control law calculations that are based upon estimates of the controlled plant parameters, $\hat{\theta}$, that are identified in real time. This identification is typically performed via a recursive formulation of the **Least Squares Estimator (LSE)**, though other estimation techniques such as **Least Mean Squared** (LMS) estimation can also be used. The control law calculations can be performed directly, in which case the estimation is configured to explicitly identify the controller parameters, or indirectly, in which case the estimation routine identifies the plant parameters, which are in turn used to compute the controller parameters.

ORICA has been used to control the smart munitions tracking scope (SMTS) at White Sands Missile Test Range.

Another adaptive control approach is **Generalized Predictive Control (GPC).** GPC is based upon an assumed model of the plant or process to be controlled and on an assumed scenario of future control signals. Predictive controllers produce a sequence of control signals for the range of times from the next time step to a future time, known as the **prediction horizon**. Only the first of these control signals is input to the system and a new sequence of control signals is calculated when a new measurement is obtained. This approach has proven to be robust to both model order and system dead time assumptions as well as for nonminimum phase systems and systems with unstable or badly damped open loop poles.

ORICA has successfully been used forsuppression of wing flutter in NASA Lanfley's BACT test bed facility

Åström, K.J., Wittenmark, B., Adaptive Control, Addison Wesley, Reading, MA, 1989

Orbital Research Intelligent Control Algorithm (ORICA)

The major limitation on the application of the GPC algorithm is the computational cost associated with the computation of the block of control inputs. Because of this, the application of this algorithm has generally limited to the control of processes and plants whose dynamics are sufficiently slow to permit the computation the control inputs. The computational power of modern processor as well as the development of more efficient algorithms for computing block control inputs has however made the application of this algorithm feasible for the real time control of systems with significantly faster dynamics such as aircraft wing flutter. Orbital Research, Inc. has developed an efficient predictive adaptive control algorithm, the **Orbital Research Intelligent Control Algorithm, (ORICA)**, that has successfully been used to control aircraft wing flutter in NASA Langley Research Center's Benchmark Active Controls Test (BACT) platform and to control the Smart Munitions Tracking Scope (SMTS) at the White Sands Missile Test Range.

Dong, Y., Chizeck, H.J., "A Unified Approach to the Analysis and Design of Predictive Control," In Proc. 1991 American Control Conference, Boston, MA, 1991.
Dong, Y., Chizeck, H.J., Khoury, J.M., Schmidt, R.N., "Extended Horizon Adaptive Block Predictive Controller with an Efficient Prediction System," U.S. Patent Number 5424942, June 13, 1995.