

# Neural Control Systems

Bernard Widrow

## **Abstract**

This talk will describe a variety of adaptive control algorithms for linear and nonlinear systems. These topics include adaptive inverse control, self-learning neural control systems, and neurointerfaces that allow human operators, providing high-level command inputs, to control complex nonlinear systems.

At present, the control of a dynamic system (the "plant") is generally done by means of feedback. Adaptive inverse control is an alternative approach that uses adaptive filtering to achieve feedforward control. Precision is attained because of the feedback incorporated in the adaptive learning. Adaptive inverse control places an adaptive filter whose transfer function converges to the inverse or reciprocal of that of the plant in cascade with it. If the plant is minimum-phase, an inverse is easily obtained. If the plant is nonminimum-phase, a delayed inverse can be obtained. Plant disturbance can be optimally controlled by a special circuit that obtains the disturbance at the plant output, filters it, and feeds it back into the plant input. The circuit works in such a way that the feedback does not alter the plant dynamic response. So, optimal disturbance control and control of dynamic response can be accomplished independently.

Self-learning neural controls apply to nonlinear plants that can be started with arbitrary initial conditions, and their neural controllers learn to bring the plants to desired final conditions. Learning is accomplished by "backpropagation through time." Applications are shown to the "truck-backer," backing a truck with one or two trailers to a loading platform, to the control of a construction crane, and to robotics.

Neurointerfaces are trainable filters that serve as couplers between human operators and nonlinear systems or plants to be controlled or directed. The purpose of the coupler is to ease the task of the human controller. The equations of a given plant are assumed to be known or at least approximately known. If the plant is unstable, it must first be stabilized by feedback. Using the plant equations, off-line automatic learning algorithms are developed for training the weights of the neurointerface. If the plant is subject to disturbance, an adaptive disturbance canceller is used to minimize the effect. The neurointerface can be adapted to be an approximate inverse of the plant, so that when it is cascaded with the plant, the overall plant response closely approximates the human command input, making it easy for the human operator to control difficult-to-control plants.