The University of California at Los Angeles (UCLA)

PROGRAM IN BASIC RESEARCH IN ADAPTIVE CONTROL THEORY

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UCLA has been the recipient of an Air Force Office of Scientific Research (AFOSR) contract for basic studies in Adaptive Control Theory. Work commenced on this contract on September 22, 1958.

At present there are five main subjects under investigation:

(1) Synthesis of multipole control systems with random signals as inputs.

(2) Time domain synthesis of multipole sampled-data systems.

(3) Synthesis of linear systems with arbitrary deterministic inputs.

(4) An exploratory study of nonlinear methods in mechanics and mathematics for possible application to control systems.

(5) The learning model approach to the design of Adaptive Control Systems.

The areas of investigation as listed above will be discussed in more detail a little later in this paper. But first the approach to the design of Adaptive Control System as taken by UCLA will be discussed.

Philosophy of Adaptive Control

Most of the papers presented at the Symposium were specifically concerned with flight control systems. As such, the work done as outlined in these papers was directed towards the fabrication of systems that would satisfactorily control aircraft. There was neither the desire or the time to generalize the techniques presented.

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The UCLA program not being constrained to the design of any particular system can afford to take a more general long range view.

Given a complete and accurate description of the vehicle or process dynamics, synthesis techniques exist which permit the design of controls for these vehicles or processes. These design techniques range from intuitive methods to very sophisticated synthesis procedures based on minimizing certain performance indices. But they do depend on a very good description of the dynamics of the system to be controlled. If the system dynamics are not accurately known or if they change during the life of the system poorer performance can be expected.

It is the purpose of the class of Adaptive Control Systems being considered here to somehow compensate for any change or lack of knowledge in the plant (vehicle or process) dynamics in such a way as to optimize system performance at all times. The many different methods proposed at this Symposium are certainly ingenious. But they are tailored to fit a specific situation.

The UCLA approach is more general in that we propose 1) to measure the plant dynamics, 2) use these measured values in the proper control equations to control the plant and 3) update the measurements if the plant dynamics are changing with time.

One of the more difficult tasks in the above procedure is the measurement of the plant dynamics. The measurements are made with the use of a learning model. The same signals which are fed to the plant are also the inputs to the learning model. The output of the learning model is compared with the output of the plant and the difference which we can term the error serves as the forcing function to an adjusting mechanism. It is the duty of the adjusting mechanism to adjust the parameters of the learning model so as to minimize some function of the error.

If the plant dynamics are changing with time the learning model becomes a parameter tracking model. Certain important questions must be asked of the performance of the learning model measuring technique:

(1) What are the ways in which a learning model can have its parameters adjusted?

(2) Is it stable? Will the learning model have its parameters adjusted so that they are a satisfactory representation of the plant dynamics?

(3) What is the dynamic performance of the learning model? How fast does the learning model respond to change in the plant dynamics? Is the learning model response (i.e., changes in its parameters) suitably damped?

Questions 2 and 3 are difficult to answer because the systems proposed are not only time varying but highly nonlinear. Some progress has been made in the short time devoted to this effort. The really heartening fact in the entire investigation is the new areas in feedback control being opened up by the questions we are asking. In fact, it seems that each question raises two more.

There are additional problems that have not yet been mentioned. One of the most serious of these problems is concerned with the operation of the learning model in a noisy environment. Finally, studies will be made on how to treat the overall design of an Adaptive Control System.

Progress of Work to Date:

(1) The synthesis of multipole control systems with random inputs for a completely free configuration has been solved. The input signals and noise may be cross-correlated or uncorrelated. This work will be presented at a forthcoming IRE national convention in New York City, March, 1959. A technical note is also being prepared for the AFOSR.

The free configuration means that a filter problem has actually been solved. At present, attention is being given to the semi-free configuration, the more nearly realistic control problem. Further investigations will include polynomial inputs in addition to random inputs and the use of finite data instead of assuming an infinite time history of the incoming signals.

(2) Time domain synthesis of multipole sampled data systems. The investigation in this area makes use of the modified Z-transform for the time domain specifications at other than sampling instants.

The multipole control problem is receiving considerable attention because we feel this area has long been neglected from an academic point of view. But more important is the fact that many of our control problems are of the multiple input-output variety and are not being tackled as though they were. In particular aircraft autopilots and jet engine controls are truly multipole systems. All of the problems pertaining to realizability conditions, nonlinearities and the like that have been investigated for single input-output systems deserve attention for multipole system.

(3) Synthesis of linear systems with arbitrary deterministic inputs. Here the input signals are not considered to be simply expressed as a polynomial. Upper bounds on allowable error are one of the specifications. The effort at present is on graphical techniques in the time domain.

(4) An exploratory study of nonlinear methods in mechanics and mathematics for possible application to control systems. The emphasis is equally distributed between searching for methods applicable to synthesis as well as analysis. Specific problems have turned up in our study of adaptive systems. In particular, we are much concerned with a class of nonlinear, time varying

differential equation of the following type:

$$\ddot{x} + a_1(\dot{x}, x, t)\,\dot{x} + a_0(\dot{x}, x, t) = f(t)$$

(5) The learning model approach to the design of adaptive systems has been described. The use of the learning model causes the simplest of these adaptive systems to fall into the general class of multipole nonlinear feedback systems.