DIGITAL COMPUTERS IN CONTROL SYSTEMS

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ABSTRACT

Contrary to the optimistic implications of some popular reporting, large-scale digital computers are still in the development stage, and their application is virtually unexplored. However, within the next two decades computers will probably be applied to automatic control systems.

Two types of control systems can use a high-speed digital computer. In one type, control consists almost entirely of information processing; the logic is simple, the procedures are repetitive, and the number of quantities controlled is very large. Examples are: control of the circulation of a weekly magazine with several million subscribers; keeping insurance records; inventory control in a large company; and military logistics.

The second type of problem, which is based on much more complex logic, is control of several interdependent quantities. An example is automatic control of air traffic, which would require computation of control instructions for up to one hundred aircraft around a busy airport. Proper instructions for each aircraft would depend on the traffic rules and the behavior of the other aircraft. By scanning information very rapidly the computer should have a virtually continuous grasp of the behavior of the whole system.

A gigantic task of computer development lies ahead, particularly in improvement of reliability. Better vacuum tubes and components, as well as the invention of new circuit elements like the transistor, are needed from the electronics industry.

The greatest impact of the computer on engineering is the expansion of the scope of automatic control. The computer will make it possible to control automatically not merely a few quantities but a dynamic situation.

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INTRODUCTION

Recently several articles on large-scale digital computing machines have appeared in newspapers and magazines, in which computers are described as, "Giant Brains," "Mechanical Brains", or "Machines That Think". The purpose of this paper is to review the status of such machines and to try to predict their progress in the next two decades. Computers show promise of expanding the field of automatic control; therefore emphasis will be on the computer's place in engineering rather than on its design or the details of its operation.

Large-scale digital computers which contain over one thousand vacuum tubes or relays are now in the early stages of development, and the machines which have been completed are generally regarded as experimental. Application of computers is a large new field which so far has only been "nibbled at the edges" without any deep penetration. Control applications are still in an exploratory study stage.

Large-scale computers have already been used for scientific computation, such as compiling tables of Bessel functions and numerical solution of difficult equations. However, the potential uses of the digital machine extend far beyond the laboratory, and within the next fifteen to twenty years it will probably be applied to automatic control. It is likely that such use will be in systems which are now controlled by groups of people.

UNIQUE FEATURES OF DIGITAL COMPUTATION

Let us examine briefly the unique properties of digital computation and the way in which it differs from the more familiar process of analog computation. Analog computation, which is performed with devices such as the ordinary slide rule, the differential analyzer, or the network analyzer, requires continuous measurement of physcial quantities within a scale model of a physical system. Contrast this with the ordinary desk calculator, which is a digital machine. In the digital machine, numbers are substituted for physical measurements, and, since digital computation is divorced from continuous measurement, accuracy is limited only by the number of significant figures available in the machine.

The comparison of analog and digital techniques reveals another important difference. The familiar analog computers, such as network analyzers, fire-control predictors, or bomb sights, are all specialized devices. It is difficult to visualize an analog machine built of cams, gears, and potentiometers which could be used to determine power system short-circuit currents and then quickly be shifted to the solution of bomb trajectories. On the other hand, the digital computer can be a general-purpose machine which requires no alteration of electrical or mechanical connections when it is given a different type of problem. In fact, a special-purpose digital machine is more complicated than a general-purpose machine.

The modern electronic computer, which represents numbers by video electrical pulses, is much faster than the older mechanical computers. If we use as a yardstick routine calculation by a skilled operator using a conventional desk calculator, we find that the electronic computer can do about the same amount of calculating in one minute that the human operator would do in a year.

The adaptability of the digital computer is a result of its freedom from continuous measurement and of the generality of the logic behind its operation. The entire solution of the most complex of machine problems is resolved into a controlled sequence of a few basic operations such as "add", "subtract", "multiply", "transfer to storage", or "compare". These basic operations, or control orders, are the building blocks of problem solution, and they can be combined like the wire and relays of a telephone exchange into a very complicated structure.

The average number of control orders available in a digital computer is only about thirty, and the computer obeys them only one at a time. The concept of solving complicated scientific problems or operating a very complex control system with so few basic operations is difficult to grasp; but consider the number of ideas expressed in all the English literature in the world and remember that all these ideas are expressed by sequential arrangements of only the twenty-six letters of our alphabet.

INFORMATION PROCESSING

So far the digital computer has been discussed as a computing device, although this name with its usual connotations is too restricted for control applications. It would be better to call the work of the computer "information processing".

Information processing can best be understood by visualizing a hypothetical application. Consider the task of controlling the circulation of a magazine which is mailed weekly to ten million readers. Applications for new subscriptions must be entered; renewals must be recorded; subscribers whose subscriptions are about to expire must be notified; lapsed subscriptions must be renewed; and sales promotion letters must be sent to groups of potential subscribers classified according to, let us say, occupation. In addition, changes of address must be entered promptly.

This is a gigantic bookkeeping problem, one in which mass production methods of information processing are an economic necessity. A large-scale digital computer might very well handle such a system, which is, in a broad sense, a control application. Since the procedures are few and simple, only a few control orders are needed; however, a large amount of information must be stored or remembered.

In the magazine problem, the computer competes with existing methods only as a faster, cheaper way to control simple repetitive procedures. There are many similar applications; for example, keeping records in an insurance company, processing census information, stock and inventory control in a large company, and the largest of all supply problems, military logistics.

COMPLEX CONTROL SYSTEMS

There is also a different class of control problems in which the logic is far more complex since the quantities controlled are interdependent. Systems of this type can be so complex and require such fast information processing that the digital computer is more than a competitor; it appears to be the only way out.

Consider now an example: the control of air traffic.

In planning for future air traffic control, Special Committee 31 of the Radio Technical Commission for Aeronautics has recommended in its official report the use of digital computers. Since this recommendation was made, popular articles have appeared which are misleading in their implication that automatic air traffic control is just around the corner. The corner is about fifteen to twenty years away and will be rounded only after a great deal more study and development of both computers and their application. Yet the computer has the potential ability to control air traffic, and as air travel expands, the now overtaxed human traffic controllers are becoming more desperate. The jet airliner will probably be the straw that breaks the camel's back.

Imagine a hypothetical problem of automatically controlling up to one hundred aircraft in the initial-approach zone of a busy airport, a zone which might be one hundred miles in radius and forty thousand feet high. Each aircraft must be given periodic instructions which will guide it along an efficient route and ensure safe separation from all other aircraft.

From data on wind conditions, choice of runway, and flight characteristics of the aircraft, plus a knowledge of the positions of all one hundred aircraft, the computer would have to calculate prescribed paths and schedules for each aircraft on the basis of known traffic rules. In this control system, the aircraft, pilot, radio navigation aids, radio communications links, and computer are all component elements. It is necessary that the computer receive control data, compute proper instructions for all one hundred aircraft, and transmit them to all aircraft once every few seconds in order to maintain continuity of control.

Conversion equipment will be necessary to translate measurements of aircraft positions into numbers for the computer and to translate numerical control instructions into proportional analog signals. The development of suitable conversion equipment is a large job which has just barely begun.

Programming the computation, or information processing, for air traffic control can be thought of as the translation into computer language of a complete manual describing the operation of the air traffic control system. The term "complete" must be taken literally, since the computer has no imagination and no originality, and can only follow the explicit instructions given to it.

The digital machine can carry out any logical process that a human controller carries out, provided that the human controller's task can be described completely by explicit instructions, and that all decisions together with the basis for each decision are completely and explicitly described.

In present-day traffic control, teams of men control large zones (about the size of New England), and each zone is subdivided into sectors which are supervised by one man. Aircraft are given a clear path through only one sector at a time, and this is a serious limitation. It would be much more desirable to clear each aircraft for its entire flight. At present this is not done because it would require a prohibitive amount of communication among controllers as they examine adjacent sectors in search of a safe route. It is characteristic of human organization that as the size of the group grows efficiency is lost because of inter-communication difficulties.

Air traffic control is a problem in information processing, and what is needed is the ability to see a complex situation as a whole. While the computer cannot actually do this at any instant, it has the advantage of being much faster than a group of people. The computer's reaction time is several orders of magnitude faster than a man's, and in speed of intercommunication its superiority over a group of men is even more impressive. The computer can scan the component pieces of information which make up the system so rapidly that it is able to approximate a continuous grasp of the whole situation.

COORDINATION OF SYSTEM DESIGN

Control applications require careful coordination of system design. The overall system requirements will influence four major characteristics of the computer:

1. Speed
2. Internal storage or memory capacity
3. Register length
4. Reliability.

As has been shown, high speed is necessary in a complex control application. The necessary internal storage is determined by each particular application. In applications like the magazine distribution system mentioned previously, the storage required would probably be so great that some cheap storage medium such as magnetic tape or magnetic drums would be desirable. The computing capacity of a digital machine is roughly the product of its storage capacity and its speed; this is analogous to the power rating of a motor, which is the product of torque and speed.

Register length - the number of digits used to express a number in the computer - can be short in control applications, only about one-half to one-third of the length needed for scientific calculation.

Reliability is of great importance in control applications. It is necessary for economical operation, and, in systems such as air traffic control, may be necessary for personal safety. A good deal of engineering work on reliability remains to be done on both circuits and components. The addition of digital computers to the growing field of industrial electronics adds pressure to the demand for more reliable vacuum tubes and circuit components. Also there is the need for invention and development of new circuit elements such as the transistor.

The introduction of the digital computer has a strong influence on the design of the control system as a whole. The need for conversion equipment to link physical quantities and numbers has already been mentioned. Another important characteristic of the digital computer is that it does only one thing at a time. When incorporated into a control system having multiple inputs or outputs, the computer is time shared; in other words, the computer is time-division multiplexed. Time sharing is well understood among communications engineers, and this understanding must be extended to the field of control engineering.

The development problems mentioned here are but a few of those which are known to exist, not to mention those which have not yet been encountered. There is already a need for more trained men to study applications, and the computer applications engineer must be at home in several fields of engineering; communications, servomechanisms, and pulsed circuits. He must also be able to obtain quickly a working knowledge of the specific field to which the computer is to be applied.

The job of developing digital computers to the stage where they are ready for commercial use is comparable in magnitude with the effort put into the war-time development of radar. Possibly computers, like radar, will experience an accelerated development for military use.

The computer's most profound influence on control engineering is the extension of our concepts of what can be accomplished by automatic control. The speed and flexibility of the digital machine, its ability to "memorize" information and correlate it, its ability to control a situation rather than a single quantity, have opened up possibilities for automatic systems which could not be controlled by any other known means.