What is a Hybrid Computer and Why

The use of the word hybrid in this context is to link the two most widely known forms of electronic computer, namely the digital computer of which most people are most aware, and which essentially works in numbers in a particular form, and the analogue computer. The analogue computer derives its name from the word analogy; in this case an exact electrical analogy, in voltages, is constructed to represent a working system, be this a mechanical plant, aeroplane in flight, chemical production plant, or whatever.

Numbers in the digital computer are represented in what is called binary form. The familiar form of calculation used is, of course, the decimal form, i.e. numbers expressed in multiples of ten. We, in Britain, are currently in the throes of converting from a duodecimal to a decimal system of counting money. When moving into the workings of a digital computer it is necessary to convert to a system of counting based on 2 rather than 10.

The representation of numbers in binary form only requires the statement of two quantities, 0 and 1

since decimal 2 = binary 10
" 3 = binary 11
" 4 = binary 100 etc.

The state of 0 or 1 can therefore mean electrically whether a voltage is present or not, i.e. whether a switch is made. The transistors of which one is otherwise familiar, perform the switching functions, in the very early machines actual switches, electromagnetically driven-relays were used.

The form of calculation that can be performed by a digital computer is essentially arithmetical, i.e. addition, subtraction, etc., but what are termed logical operations based on the algebra of the binary form are included.

The analogue computer, however, is quite different in that it solves differential equations, rather than arithmetic and algebraic equations, although these are not excluded and do, in fact, form part of the total analogy. The velocity or speed of a vehicle is the first differential of its position along a given path or road, while its acceleration is the second differential. The equations presented to the analogue computer are in this form, i.e. displacement, velocity and acceleration or their equivalents.

The complete set of equations which represent, say, a motor car travelling along a road, to include the effect of the drivers action, the bends in the road, the road roughness, the movement of the car suspension etc, are solved simultaneously, so that it can be said that the true history in time of the movement of the car can be represented by the voltage variations in time calculated by the analogue computer.

When considering the hybrid computer, the first requirement is to communicate the two dissimilar forms of data, i.e. numbers in binary form and voltages, this is done through analogue to digital converter - which successively divide the voltage present by factors of 2, and digital to analogue converters which reconstruct voltages from the binary value by multiplying a given basic voltage by factors of 2.

The control of the two computers working together form the other major task.

With the achievement of a hybrid computer the value of the total system is many times greater than the sum of the two component parts, as can be easily imagined from the scope of problems that are now possible.

Facilities - Vital Statistics

The group's facilities are essentially grouped into

(a) that for basic experiment and research.

(b) that associated with computing and the application of computers.

(c) that for instrumentation, which in the main bridges the first two in that instrumentation of experiments and processes is aimed at producing computer intelligible data.

The facilities for experiment are centred in the main Laboratory which provides a comprehensive selection of electronic instruments and test gear and workshop facilities.

The computing facilities are:

(i) The access to the large digital computer, Titan, sited at the Mathematical Laboratory. Two remote teleprinter consoles are provided and are situated along with the other comparable machines for paper tape preparation.

(ii) The hybrid computer. This comprises an I.C.L. 4130 digital computer linked to PACE 231R V analogue computers. There are in fact four such analogue computers, all of which can, however, be linked together in the solution of a large problem. They are physically divided into two groups of two consoles. Those remote from the digital cannot be controlled except indirectly from the 4130 digital. However, the group of analogues directly adjacent to the digital computer are fully interfaced to the digital in terms of data, logic and control and addressing.

The group also possess two major data logging facilities for the collection of data from industrial plant. One set is designed to operate on slow processes such as encountered in chemical engineering and in consequence, the system has been designed to collect the data on to punched paper tape for subsequent analysis on the 4130 digital, and in such a way that the logger may be left to collect the data automatically over extended periods of time amounting to months, when the only attention required is to replace the used reels of paper with new ones.

A second set is in the process of manufacture and is intended for the collection of data on fast processes - usually mechanical, such as the production of steel sheet in a rolling mill. There it is essential to use the much faster recording rate possible with the magnetic tape machine, and to record in a form suitable for replay on the 4130 digital magnetic tape decks. This fast data logger uses a small digital computer as the controlling device.

Vital Statistics of the Hybrid Computing system

I.C.L. 4130 digital

Store size: 32,768 words
24 bit words
2μsec store access time.

4 Magnetic tape handlers: 33/12 Kch/sec.

Line printer: 300 lines/minute. 120 ch frame

Digital plotter: 12" paper width
200 steps/sec.
0.005 inches per step.

2 tape readers: 1000ch/sec.

2 tape punches: 110ch/sec.

1 teletype controller: 10ch/sec.

Central processor fitted with autonomous transfer.

PACE 231R Vs together:

60 Integrator amplifiers
112 other amplifiers
18 multipliers
80 servo-set potentiometers
40 potentiometers
20 function generators
20 comparators
12 limiters
16 track store units
24 AND gates
20 relay drivers
16 D/A switches

PACE 231R and 221R, together:

48 Integrator amplifiers
62 other amplifiers
21 multipliers
6 squarers
160 potentiometers
12 function generators
10 comparators

Interface to 4130

48 analogue to digital converters
64 digital to analogue converters
16 logic trunks
13 interrupt trunks

Full control and addressing.

"So you think you've got problems!" or
"How to use a hybrid computer"

To explain the use of the facilities available in this Department consider that the problem concerns a hypothetical chemical plant, currently in use and earning its keep. The plant management will be aware that the plant produces scrap when it starts up and is shut down as the product does not meet the minimum quality control requirements. The management also is aware that during a typical day further product will also be scrapped because of, for example, hopper levels changing or feed water flows altering to less than optimum levels etc. These may be small in themselves and probably the scrap product has not even been attributed to these disturbances. (If the product takes fifteen minutes to make then a disturbance at the start of manufacture may not be detected until it reaches Quality Control some five minutes or more after it has left the production line - 20 minutes after the causative disturbance.) The disturbing factors may themselves be very small but two or more values being less than optimum may be very significant in the performance of the plant.

This is where the Control Engineer steps in. A preliminary study of the plant will reveal where the major factors affecting performance may be measured and he will initiate the gathering of data from the plant and recording on to punched paper tape or magnetic tape.

He will synthesise a mathematical model of the plant based on the chemistry of the process and on the data and physical information he has gathered. He will make intelligent guesses at the unknown coefficients of his model and will estimate the most favourable values to fit the data using an iterative process called hill climbing. The resultant represents an accurate mathematical model of the plant. This model is next converted into a set of first order differential equations and by matrix manipulation and transformation of the coefficients a reduced model is obtained which contains all the dominant disturbing factors which grossly affect the performance of the real plant. This model may be patched on the analogue part of the hybrid system for the study of how the plant variables affect one another and change with time. The recorded disturbances and data may be "played" to the model through the digital computer to confirm that it performs like the real plant.

Optimising control strategies may now be tried out on the model to evolve the ideal. The Control Engineer is aided in his task by being able to study the plant on totally different time scales from that of the real time operation - a year's performance may be simulated in a matter of hours.

Production on the chemical plant will not have been affected whilst the plant was studied and yet, having identified the sensitive areas, the Control Engineer is able to advise where it will be necessary to regulate and control the chemical plant to achieve greater efficiency and a better quality product.

Postgraduate Research work in Control and Systems Engineering leading to the M.Sc. and Ph.D. Degrees

A candidate for a higher degree is required to devote at least six terms to full time research before proceeding to the M.Sc. degree and at least nine terms before proceeding to the Ph.D. degree. For three of these terms a candidate must be resident in Cambridge and, if not already a Cambridge graduate, a further three terms residence in Cambridge is required. Provided the residence qualification has been satisfied, permission may be granted for the candidate to work away from Cambridge for all but one year, provided he is fully employed during that period on his approved subject of research. Each candidate is examined by means of a dissertation, written at the end of his research period, followed by an oral examination.

A research student will not in the first instance be registered for a degree. After two terms of residence he will be required to write a brief report on his chosen research covering a literature survey, such work as he has carried out in his first two terms and a description of the further work he proposes to do. The Head of the Research Group and his research supervisor will discuss the report with him and it will later be decided whether he shall be registered for the M.Sc. degree or Ph.D. or whether he should be advised that it is not in his interest to proceed further with University research work.

The programme of research in the field of control and systems engineering being carried on in the Engineering Department is aimed at the development of generally applicable methods of analysis and optimisation of non-linear control systems and filters with random inputs, it includes the following areas of work:

Theoretical and experimental investigation of methods of optimisation of non-linear control systems and filters.

The use of functionals and the application of methods of statistical mechanics to control system analysis and synthesis.

Methods of parameter estimation and the development of mathematical models of complex systems.

General methods for the design of optimal and insensitive multivariable control systems.

Theoretical and experimental investigation of methods of non-linear control systems and filters.

Analysis and optimisation of control systems with randomly varying loads.
Recording and analysis of random processes.
Application of analogue, digital and hybrid computers to the control of complex industrial plant, aircraft and economic systems.
Use of analogue, digital and hybrid computers in control system design and the preparation of universally applicable design procedures.
Analytic techniques associated with hybrid computation.
Important classes of control systems such as on/off and saturating systems, multi-loop adaptive and predictive control systems.
Analysis and optimisation of extremum regulators.
Analytic and programming techniques associated with hybrid computation.
Self-adjusting non-linear filters and plant models.
Development of sub-optimal control systems, and the determination of their performance in relation to optimal systems.

Some current Research Topics

The Application of Control Theory to Macro-Economic Models

undertaken by D.A. Livesey

A macro-economic model of the U.K. economy has now been built which consists of sixteen nonlinear differential equations, with five controls and two exogenous indices. The model, based upon a set of six accounting equations, explains the behaviour of the main aggregated economic variables. The model's parameters have been obtained by fitting, for quarterly data, estimated values of the variables to actual variable values over the period 1957-66. The equations have been fitted both as single equation models using ordinary least squares and as a complete set of simultaneous equations using a hill-climbing technique.

The model has been programmed as a computer game on the university TITAN computer. The player can set the taxation rates, government expenditure and the bank rate for several years. The resultant behaviour of the economy is determined by the model. The output from the game is in the form of the standard accounting tables published by the government. At present the game is under evaluation for use in undergraduate teaching in the Faculty of Economics.

Dynamic response tests have been carried out to evaluate the structural accuracy of the model. One or two weaknesses are at present being corrected and the project will move into the final stage shortly. The model has been constructed so that control algorithms can be applied. It is expected to be able to demonstrate the improvement, measured according to some criterion, which results in comparison with the actual events over the same period.

An Automatic Landing Control System for a V.T.O.L. Aircraft

undertaken by C.R. Guy

The object of this research project is to design, and mechanise using the hybrid computing facility, an automatic landing control system for a vertical take-off/landing (V.T.O.L.) aircraft.

For such a manoeuvre to be accomplished the aircraft is required to follow a given flight path. This can be broken down into two separate parts thus:

1. the approach region.
2. the touch-down region.

As both the dynamics of the aircraft and the form of the controller are different for the two flight path regions, the project can be divided into two halves.

A model of an aircraft has been set up on two analogue computers. This model is based on the SHORT S.C.1. V.T.O.L. research aircraft, and represents motion of this aircraft in six degrees of freedom for low speed flight conditions (i.e. flight in the touch-down region).

A touch-down controller is at present being developed for use with the model. As this problem is characterised by the necessity of satisfying multiple performance requirements and constraints, the controller design lends itself to the use of optimization theory. The system being developed uses optimization theory to establish the form of the time varying feedback gains. When the design of the controller is finalised, the complete system will be set up on the hybrid computing facility.

Future work will include developing the model for the transition and wing-borne regions of the flight envelope, and mechanising a complete landing system.

Study of a Nitric Acid plant

undertaken by V. Sobotka.

A model of an absorption column has been constructed. Such a plant is a part of factories which produce nitric acid. The main demands on these plants are to keep the concentration of nitric acid constant, to produce as much acid as possible and to keep the concentration of waste gas very small.

The whole model of the plant has two different parts. It is firstly a model of the connecting pipes and valves among the towers of the column and secondly a model of each tower. Account has to be taken of all those factors which influence the desired output values.

It is not very difficult to construct the model for the physical part of the plant because the time constants are relatively small and the origin of the different disturbances is readily determined.

The second part of the model is more complicated because the chemical reactions which occur inside the absorption towers are not very well known. Many attempts have been made by different chemists to discover the equations for such a process. The articles about their results are written only about small columns in laboratories and there is no proof that it is possible to generalise these results for big plants.

It will be necessary to compare and to verify these equations with the experimental data about the plant which are being obtained from Czechoslovakia during the summer.