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ESCORT: A DATA ACQUISITION AND DISPLAY SYSTEM TO SUPPORT RESEARCH TESTING

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16. Abstract

Lewis Research Center of NASA has been involved in the design and implementation of data acqusition systems to serve its many research testing facilities for about 25 years. Initially, data acquisition and recording were handled as separate functions from processing. With the advent of the minicomputer and microcomputer, these functions have been combined to provide rapidly updated displays in engineering units of selected data. This allows the researcher to expedite testing and acquire data in the specific areas of interest. Lewis' approach to system design takes into account maximum utilization of equipment, backup capability, off-the-shelf system availability, modular approach to both hardware and software, and provision for program development and checkout independent of the system on which it is to be used. The system to be described, known as Escort, is currently being installed at many of the small to medium-sized research test facilities at Lewis. Primarily designed to acquire data at steady-state test conditions, the system can also monitor slow transients such as those generated in moving to a new test condition. The system configuration makes use of a microcomputer at the test site which acts as a communications multiplexer between the measurement and display devices and a centrally located minicomputer. A variety of measurement and display devices are supported using a modular approach. This allows each system to be configured with the proper combination of devices to meet the specific test requirements, while still leaving the option to add special interfaces when needed. Centralization of the minicomputer improves utilization through sharing. The creation of a pool of minis to provide data acquisition and display services to a variable number of running tests offers other important advantages which will be discussed.

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E-9644

THE ENVIRONMENT

Lewis Research Center of the National Aeronautics and Space Administration is engaged in the development and testing of a wide variety of hardware. Most of this is in some way related to propulsion or power systems for aeronautics, space, or ground based applications. The environment consists of large numbers of research testing facilities ranging in size from the 10x10 foot supersonic wind tunnel down to the life testing of batteries.

In conducting this experimental testing, large numbers of data measurements such as pressures, temperatures, forces, flows, speeds, voltages, and currents must be made and entered into equations in order to determine performance. Since this is a research environment, relatively high accuracy is usually required. Both static and dynamic measurements are often necessary.

Because of the inherent differences in the measurement technique, analysis, and presentation of results of static and dynamic data, separate data acquisition and processing systems have usually been designed to perform these two functions. The system to be described addresses the problem of acquiring and processing static data measurements for the on-line analysis of research experiments.

The research test facilities at Lewis are scattered over a 340 acre area. In most cases, provision has been made to run special-purpose cables underground to provide for data communications to a central location. The concept of centralized data recording and processing has been generally followed for nearly 25 years, with special-purpose on-site systems installed only when necessary. The objective was to standardize hardware and software support to minimize costs in both manpower and hardware, and to achieve a high degree of reliability.

THE PROBLEM AND OBJECTIVES

The basic problem of supporting a typical research test has not changed significantly over the years. What has changed dramatically, are the possible solutions to the problem created by the state-of-the-art explosion in the computer field. These changes have made it possible for the research engineer to have a much more intimate and detailed understanding of the experiment during a test. Functions previously requiring a large scale computer for support can now be performed using mini and micro computers.

It was obvious, at the beginning of the minicomputer revolution, that the best technical solution was to install a minicomputer-based system at each test facility. The system was configured and programmed to match the individual requirements of each location, and therefore able to best accomplish that specific task. The user was expected to provide whatever software might be required over and above some standard modules which were supplied.

A number of things were learned as the result of installing several systems using this philosophy. Hardware configurations tended to be customized, and therefore difficult to maintain. Although initially the users were enthusiastic about becoming ivolved in programming a computer, this eventually resulted in their not being available for the job for which they were hired--to conduct research tests and develop hardware in their field. Documentation of both hardware and software was difficult to maintain in a form that another person could follow if necessary. Pressure soon developed to provide software support from a central group of programmers, or to hire a programmer for each machine.

As a result of these developments, a new look was taken at how to provide adequate data acquisition and processing services for a large number of research test facilities, taking into account both the technical and the management problems involved.

Keeping this in mind as a main objective, the following system design criteria were established:

Locate Minicomputers Centrally

This will permit assignment to tasks on an as-needed basis. Computing power can be matched to research requirements through a hierarchy of minicomputers having several levels of power and speed, including networking to large processors where necessary.

Configuration Flexibility

Design a base hardware and software package along with an assortment of pre-tested options to meet the majority of the known requirements, leaving the option for a limited number of unique functions.

Off The Shelf Availability

A major problem in the development of custom systems had been the one to two year lead time necessary for total procurement and implementation. The goal is to be able to provide a working data acquisition and display system two or three weeks following requirements definitions.

Minimize Experiment-Unique Custom Programming

Provide user-oriented tools to accomplish the tasks which make experiment-unique programming necessary.

Minimize Downtime

Utilize quick-change, standard modules in the design, backed up by available spares, and a thorough field maintenance training program.

Develop And Pre-Test All Hardware And Software

Create a mock test facility in the central area, to make possible the development and testing of all hardware and software modules, before installing in a research test facility.

Stress Human Engineering

Employ current computer technology to eliminate the need for the user to be a "computer expert".

THE APPROACH

With the above criteria and constraints in mind, a system called Escort was configured which allows all of the input-output devices necessary at the test facility to be connected to a centrally located minicomputer via a few wire pairs. A microcomputer at the test facility serves as a communications multiplexer, sorting all messages between each of the devices and the central minicomputer (Fig. 1).

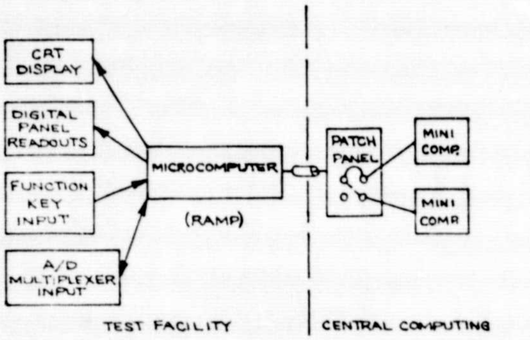

Fig. 1. Escort Configuration

This is known as a Remote Acquisition Micro Processor (RAMP). At the central computing area, the wire pairs from the microcomputer are terminated in a patch panel, where they can be jumpered to any mini in the pool. The minis in the pool are hardware and software compatible between machines of the same level, and upward compatible with machines of a higher level of computing power, speed, or capacity.

The total data acquisition, archival recording, and processing path is shown in Figure 2.

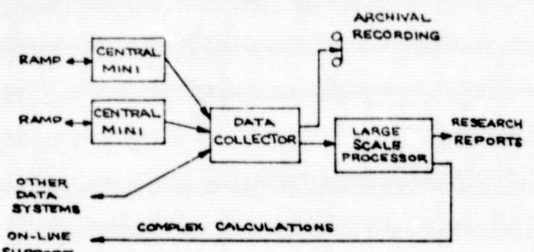

Fig. 2. Total Processing Path

Here, the Escort system, consisting of the RAMP and central minicomputer, is shown as it is used in conjunction with two other major elements which support the research testing. The Data Collector is a minicomputer based system which provides archival recording for a large number of Escort and other data acquisition systems. It also provides a communication link to a large central processor.

The large-scale central processor is a time-sharing machine capable of providing complex on-line calculations back to the test facility. Depending upon the nature of the research test, and the complexity of the analysis, this machine may be used to augment the on-line computing support contributed by Escort. It also does all of the computation necessary for the preparation of research reports, including preparation of graphics and microfilm.

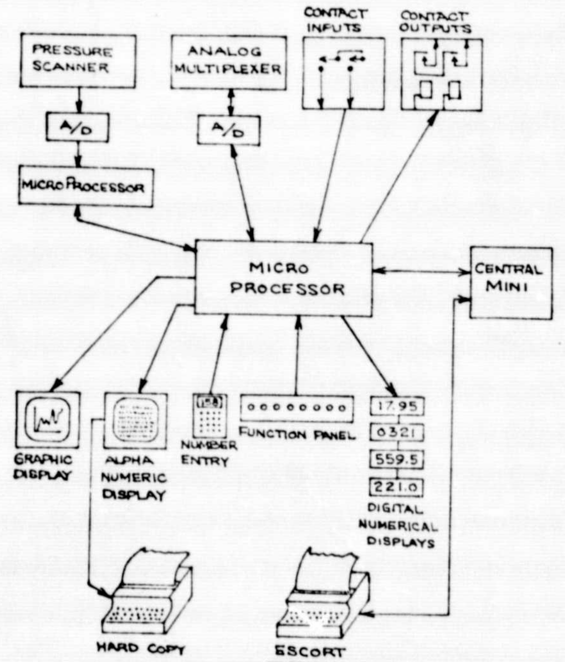

Fig. 3. RAMP Configuration

RAMP Configuration

The RAMP serves as a communications multiplexer to devices which communicate with the experiment and the experimentor. All of this information is relayed back and forth from the central minicomputer. Figure 3 shows the RAMP, with devices which talk with the experiment on the top, and devices which talk with the experimentor on the bottom.

Experiment Communication will be discussed first. In typical test facilities, the basic input device is the analog multiplexer and analog-to-digital converter (MUX-A/D) which provides the means for measuring large numbers of analog signals in the volt or millivolt range. Thermocouples, strain gages, pressure transducers, and any other instrumentation, which generate a signal in the form of an analog voltage, are interfaced to the system through an analog MUX-A/D. Most data is acquired through this path.

A second method for introducing data into the system is through pressure scanning switches. These are widely used for pressure measurements because they are a less expensive alternative to using a pressure transducer for every pressure channel. They make use of a mechanical pressure switch to connect a single tranducer sequentially to a number of pressures to be measured. Another microcomputer controls this scanning and the temporary storage of measurements.

The most recent sample of all pressures measured is transferred from the pressure scanner micro to the RAMP micro on request.

A third method for introducing data into the system is through contact closures. The standard RAMP senses up to 24 contact closure inputs. Since the same mechanism is used for function switches (discussed later) and contact closure sensing, it is actually the sum of these which cannot exceed 24. These numbers apply only to a standard system, however, and could be increased to meet special requirements.

Contact outputs are used for communication both to the experiment and the experimentor. They can be used for such purposes as stopping the experiment when an unsafe or out-of-range condition exists. They may also be used to sound an alarm to alert an operator to a similar, or less serious condition.

Operator Communication peripherals shown at the bottom of Figure 3, are as follows: (1) Alpha-Numeric CRT; (2) digital numerical displays; (3) function switches; (4) number entry panel; (5) Graphic CRT Display; and (6) hard copy printer and keyboard.

The alpha-numeric display is the primary monitoring device used in the test facility. It is often used with a buffered printer to allow the contents of the screen to be printed without interfering significantly with the dynamic update of the screen. Two of these devices are sometimes used in a typical installation. One is used to monitor the experiment, while the other is used to monitor the test facility which sets the test conditions. Generally up to 40 parameters with labels can be displayed and dynamically updated on each screen.

A graphic display, with or without hardcopy, can also be used to create a continuously updated performance curve. Bar charts or multiple line graphs are possible.

Another method of continuous monitoring of test facility parameters is by means of digital numerical displays, which are numbers formed by light-emitting diodes. These are generally used in applications where a few specific parameters must be continuously displayed and updated at various locations in a control room for operator use. Up to 15 five-digit numbers (five digits, sign, and decimal point) may be displayed in this way in a standard system.

Functions switches are simply pushbutton switches, each of which has been assigned a specific function. The functions assigned these switches are implemented by means of software and so can differ between test facilities, conforming to specific requirements. Function switches are used to initiate system actions which must be taken repeatedly in the typical operation of a test facility. Some common usages are: "Record a Data Point", "Make a Hard Copy of CRT Display", "Display a Different Set of CRT Parameters", etc.

Up to 24 function switches can be incorporated in a standard system. However, the sum of function switches plus contact closure inputs cannot exceed 24, as mentioned previously.

The number entry panel provides a mechanism for entering numbers into the system for specific purposes. It is used in conjunction with the function panel for initiating functions which have a number associated with them. For example, "Display Parameter List Number Three on the CRT." A number up to 256 can be entered by means of a calculator-type number keyboard and display register.

The Escort terminal shown on Figure 3 is interfaced directly to the central minicomputer. It is used for facility interaction with the central minicomputer, for logging events, and for error reporting. Typical uses for this device might be to change limits in a limit checking calculation or to remove certain parameters from an averaging calculation.

RAMP Operation

The RAMP can acquire data from all of the above instruments and service the monitoring devices and control panel. It both sends and receives command and data messages to and from the minicomputer. The RAMP is, with one exception, a slave to the minicomputer. All of its actions are initiated by commands embedded in messages from the mini. As an example, the mini may request a scan of the multiplexed A/D channels. The RAMP would perform the scan using a pre-stored address pattern and then transmit the data to the mini. The function switches, however, are handled in a unique way. The RAMP senses the status of all the contacts and responds to each change by sending a message to the mini containing the current status of all the contacts plus the value stored in the number entry panel.

The RAMP makes both longitudinal and vertical checks on messages to detect any communication errors caused by noise on the line connecting the two processors, and requests a repeat transmission if any are present. It continues to request repeats until the transmission is validated, or until it is clear that the line is defective (at present this is concluded after six successive failures). The minicomputer makes similar checks at its end.

Character data sent to the displays may be either verified or not verified depending upon requirements. When the application is such that a single error is not tolerable (e.g., output to a programmable controller), the verified mode is used. Data in error is not sent to the display device and a retransmission from the mini is requested. Somewhat faster throughput may be realized in the non-verified mode. The communication lines have a very low error rate and errors are corrected on the next update. If updates are occurring frequently (e.g., once per second), it is faster to let the problem clear itself with a new update than to make an effort to retransmit the old data.

The RAMP contains a "watchdog timer" which notifies the facility of a possible failure in the minicomputer or communication line wherever it does not receive any requests for data within a selectable interval (nominally 15 seconds). It uses contact output number 20 for this purpose.

Central Minicomputer Configuration

There are three different levels of support provided by the central minicomputers, depending upon the requirements of the particular test. These are designated Escort I, Escort II, and Escort Multi-Application. The basic chracteristics of these three machines follow. All use a 16 bit general purpose minicomputer.

Escort I operates under a real-time executive utilizing a foreground/background mode, supported by 32K words of magnetic core storage and a 2.5 megabyte disc. It is dedicated to one test facility at a time.

Escort II operates under a multi-task real-time executive supported by 64K words of magnetic core storage, two 2.5 megabyte discs, and floating point hardware. It is dedicated to one test facility at a time.

Escort M/A operates under a multi-task real-time executive supported by 96K words of magnetic core storage, three 2.5 megabyte discs, and floating point hardware. It serves multiple test facilities at a time.

Assignment of a research test to a particular machine follows these general criteria. Tests which require on-line display support with less than 200 channels of data are assigned to Escort I. Those which require on-line display support and have more than 200 channels use Escort II. Tests which do not require on-line display support, such as life tests, use the Escort M/A.

SERVICES PROVIDED

Escort provides the researcher and test engineer with a wide variety of services ranging from data recording to facility monitoring and the playback of essential test parameters. This section describes those options which are an integral part of the system and can be supplied "off the shelf". However, Escort may be modified, where necessary, to fulfill requirements not covered by the standard options.

Data Recording

Escort acquires data in a burst mode at one-second intervals in order to provide a continuous update of monitors and playback services. Normally this data is processed and then discarded, but it can be permanently recorded. A "reading" can be recorded either manually by be pressing a pushbutton on Escort's function panel, or automatically through the use of a schedule entered into Escort's clock facility. It is also possible to invoke data recording through user-supplied contact closure or when some signal exceeds a pre-established threshold.

History File

Some portion of the data acquired by Escort can be temporarily stored in a History File for later reference. This file is especially useful in experiments where there may be unpredictable failures or other special events which can only be analyzed if there exists detailed information on the conditions proceeding them. The file is also useful, however, for referring back to previous conditions or for verifying the reproducibility of the data. Thus the History File can provide a kind of slow motion "instant replay" of data written on it.

The History File can be thought of as a simple ring buffer in which the oldest data is continually being overwritten by new data. The length of time that data is stored is determined by the size of the ring, the size of a scan of data, and how often data is written into the file.

The History File can be configured so that it is updated either by pressing a button on the control panel or by simply specifying that every "Nth" scan be recorded. In this case, the occurrence of the special event must freeze the file to prevent the important information from being overwritten. The system can recognize an event from contact closure, a limit violation, or the pressing of a button on the front panel. Some "past history" or data following the event can be included by specifying that the "freeze" should occur so many scans after the event trigger.

Experiment Data Monitoring

Escort provides an alpha-numeric CRT for experiment data monitoring. A display editor allows the user to design his own display format. The information presented on this device can be data in millivolts, data in engineering units, or derived quantities. The acquisition time and date, barometer, display number, test identification, and an indication of millivolts or engineering units are included with each display for a reference. Many experiments and tests contain more information than can be placed on one or even two CRT screens. Frequently it is desirable to see different subsets of information at different times. Escort supports this need by providing up to 16 predefined display pages which can be selected by entering a number into the number entry panel and then pushing the DISPLAY function button. If another pattern is selected and it is desired to return to the previous one, it can be recovered simply by hitting the LAST DISPLAY button. In this way the user can alternate between two patterns without reentering the pattern numbers or can easily work between a primary pattern and several alternatives.

Facility Data Monitoring

Escort provides four aids to the operation and monitoring of the facility:

1. Operator displays.

2. Limit Checking.

3. Contact closure programs.

4. Operation Log.

A separate display capability has been dedicated to the playback of important operations parameters as distinct from research data. The parameters can be either measured or derived and can be represented in either millivolts or engineering units. The operator's displays are not pushbutton selectable as is the research CRT display. The update rate may be higher than that of the research monitor. The display device may be a set of up to 15 discrete digital panel meters similar to those found on calculators, or alternately an alpha-numeric CRT similar to the experiment CRT. The advantage of the discrete meters is that individual parameters may be displayed where they are the most convenient whereas a CRT is able to present more information and can include labels and explanatory comments.

Escort can be used to automatically monitor a number of signals which must be kept within predefined limits. The values of the limits, either upper, lower, or window, can be entered in engineering units. The system will then compare the signals against their limits every time data is acquired. If one is out of limits a prescribed number of times in a row (from 1 to 15), Escort will notify the operator and possibly take some emergency action. Three types of alarms are provided: (1) A typeout on the facility log of the time, word number and limit which was exceeded; (2) A "summation" contact closure which is activated when any limit is violated and can be used to drive an out-of-limits audible or visual alarm; and (3) Up to 14 individual contact closures, each of which can be assigned to one or more channels and which can be used to drive alarm panels. Two sets of limits can be assigned to a channel, one which invokes the above warnings and one which also takes some action such as shutting down the facility and freezing the history file.

RESULTS

Although all the features of the Escort concept have not been fully developed at this time, 12 RAMPS have been installed at test facilities and are operational. Considerable experience has been gained in adapting the modular approach to a wide variety of research tests, and in training both professionals and technicians to use the system. As might be expected, this experience has resulted in some minor modifications to certain features in the system, but the basic concepts have proven to be workable. Especially gratifying is the fact that all of the initial objectives appear to have been attained.

User Reaction and Observations

The user community is comprised of a wide variety of scientists and technicians, some of whom have used computerized systems, and some who have not. Those who have been using computers in a hands-on mode feel that Escort is limited in its capabilities, particularly with regard to what can be done to program the system for specific calculations or functions. Those who have no experience with computers find Escort to be a valuable tool in running experiments because it allows them to see and monitor variables which they could not see previously.

A major concern on the part of many users, prior to having any experience with the system, had to do with the limitations of the communication line between the micro and the central mini. The update rate of the system is presently limited by the 10K bit rate on this line. Experience with the present users and tests has shown that an update of all displayed data is desired at intervals of once every second or two. Although some of the installations are coming close to this rate, many are taking about twice this long. Analysis of the total system update limitations has shown that although the communications line could be driven at twice the present speed, the method by which the data enters the minicomputer would have to be changed to take full advantage of the speed. Both of these steps are being considered if the update rate becomes a serious problem.

The other major concern, especially on the part of experienced computer users, is the fact that the minicomputer has been removed from the test facility, and is therefore not as accessible to custom program a job. This is probably the most controversial aspect of the Escort concept, and one which deserves some discussion at this point.

The decision to move the minicomputer to a central location was based on management concerns and problems more than on technical reasons. Most system designs are the result of compromises between technical requirements and marketing, manufacturing, servicing, and programming support requirements. The constraints placed on the design of Escort resulted in compromises between technical requirements and management and support requirements. It was well recognized that we were dealing with a broad spectrum of users within a scientific community, and that the system supplied would have to meet the minimum requirements of most of the jobs. It was also recognized that many of the users would not be able to provide programming support for their system, and that this would have to be supplied by a central programming group which was severely limited in manpower. Experience with custom local systems previously showed that although there was some interest in users doing their own programming, frequent complaints from their management indicated that the user was not spending his time doing the work for which he was hired. The responsibility for supplying programming for the system often reverted to the central group, at which time it was discovered that the documentation was in a chaotic state, and most work had to be redone from scratch. This resulted in very poor utilization of the central programmers. Since most of the programming support would ultimately be done by the central group, it was decided that the system design should make good use of their time and efforts. The philosophy was adopted that Escort systems should have full hardware and software support from the time that the system is installed until it is removed from service to be used in another application. With this concept, the researcher can use the system as a data acquisition and display tool without being burdened with the task of learning programming or understanding the internal workings of computers.

As a result of concentrating the minis in one area, the central programming group spends its time working rather than travelling to remote locations. Documentation is well maintained, and there is good consistency with regard to how jobs are programmed. It is much easier for one programmer to take over the work of another if necessary. Because of a number of similar machines in the central area, program development rarely interferes with running a test facility. Also, if a test facility runs into difficulty, there is a programmer usually available to assist.

Test Facility Simulator

Early in the development phase of Escort it was recognized that a test facility simulator would be needed in the central area to develop and check out both hardware and software. This eliminated the difficulties related to trying to debug problems between two widely separated parts of the system. In addition, developmental work could proceed prior to, and during, the installation of a new system. This concept turned out to be so advantageous that a second simulator was installed.

Although the simulators are busy most of the time on software development, they have also turned out to be valuable in training new users. Demonstrations can be set up in a controlled environment, and the user can see what happens at both ends.

Installed Systems

Twelve RAMP systems are currently installed in the field, with new systems going in at the rate of about one a month. Research tests being conducted using these systems vary widely, and make use of all three levels of support available under Escort. Following is a list of tests being conducted.

- Full scale jet engine
- High temp. high pressure compressor
- Jet engine combustor
- Diesel engine
- Gas turbine automobile engine
- Ion thruster
- Vertical lift fan
- Anechoic chamber analyzer
- High power gas laser
- Solar radiation
- Photovoltaic array
- Shuttle seal

Improved Implementation Times

One of the objectives in going to the Escort concept was to reduce the time required to provide a system to a new user. With custom-specified systems installed at the test facility, between one and two years lead time had been our experience.

Because of the modular design of the RAMP, it can easily and quickly be configured to meet most of the requirements which are encountered. Since the design incorporates a standard set of options for all systems, a sufficient number of modules of all types can be kept on hand to provide for both new installations and spare parts.

Because of the flexibility in the central mini area to assign computers on an as-needed basis, it isn't always necessary to buy a new computer when a new job comes in. There is a sufficient number of computers in the pool to handle a practical worst-case running schedule of the test facilities, while still not requiring a computer for each test facility having a RAMP. Some tests are run on different shifts, which also aids sharing.

As a result, the objective of being able to install a working system in a few weeks from the time of requirements definition has become a reality. This was proven in a particular case when a researcher found a need to quickly acquire data on seals to be used in the Space Shuttle. The system was configured, installed, some small amount of custom software developed and combined with standard software modules, and made operational three weeks from the time that the job was defined. Not only was the job done quickly, but a new phenomenon in choked flows was observed which had not been seen with the previous data recording system.

CONCLUSION

Considering both the technical and management problems related to providing on-line data acquisition and display services for a large number and variety of research tests, the Escort concept has combined minicomputer and microcomputer in a unique way to meet this objective. Neither system performance in terms of speed or technical characteristics are worthy of being reported, but the ability to solve a data acquisition and display problem quickly and with a minimum of effort is worth noting.

Escort is still under development, particularly in the areas of graphics support and direct digital communication to special purpose instruments. It is expected that ultimately upwards of 40 or more test facilities will be served by Escort systems at the center.