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# A DATA ACQUISITION AND CONTROL SYSTEM FOR THE 46 M TELESCOPE AT THE ALGONQUIN PARK RADIO OBSERVATORY

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The major instrument at the Algonquin Radio Observatory is a 46 m Alt-Azimuth telescope that is useful down to a wavelength of 1–2 cm. During observations the telescope is optically slaved to the position of a master equatorial (ME) unit situated at the axes of the telescope. Scan rates of up to 2.4 degrees per min are effected via constant rate servo systems on the ME drives. Excluding refraction and telescope deflections the overall accuracy of the system is better than 10 arcsec. Shaft encoders are sampled periodically in order to provide the telescope and ME coordinates to 18 and 20 (1.25″) bits of accuracy respectively.

When the telescope was nearing completion in 1965 an in-house group consisting of members from the Radio Astronomy and Data System sections was formed to plan, purchase and program a data acquisition and control system. Unfortunately the decision to postpone the control phase was taken after plans were completed. However, a computer system capable of handling both phases was installed at the end of 1967 and the data acquisition phase was completed in 1969. The decision to proceed with computer control was taken in 1970 and the control system is now ready.

The computer system consists of a 24 bit, 1.75 μs CPU with 20 K words of memory. Two heavy duty teletype keyboard/printer units are used as command devices for the foreground and background users. The system also has two 45 ips, triple density, 7 track tape drives. Under normal operation one drive contains a system tape and the other drive is used to write data. A high speed paper tape reader and punch are available to the background user except when pre-empted for a few foreground uses. A custom I/O unit was built to interface the telescope, receivers, control desk and other auxiliary equipment. For computer control the following interfaces are needed:

a) 3 channels of bipolar analog input
b) 4 channels of bipolar analog output
c) 6–24 bit words of discrete input
d) 7–16 bit words of discrete output.

An observer's console has also been added to provide the following features:

a) approximately 40 of the 100 commands can be effected with push buttons
b) the salient status conditions can be monitored
c) 24 operator switches can be set to control certain modes of operation (primarily used for custom processing subroutines)
d) 2 eight digit numeric displays for monitoring data such as coordinates, parallactic angles, focus position, etc.

The operational environment at ARO dictated the type of system that evolved. Since this is a national facility and since it is an open shop operation (each user must be on site to direct his observing program) the following features were necessary:

a) the system must be capable of providing a wide range of services with minimal training and no additional programming,
b) it must not severely limit those who are willing to develop on-line processing programs,
c) it must permit the users to share programs.

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In order to make the system as natural and consistent to use as possible the basic unit of observation for the data acquisition, the control, the on-line processing and the post-processing phases were chosen as the scan. To take a scan the user must specify the parameters that define the scan and simply enable the system. If operating in the computer control mode the scan will be taken automatically. The coordinate along which the scan is taken is called the pilot or *P* coordinate and it must be one of the following coordinates: AZ, ZA, HA, Dec., RA, RA1950.0, Dec. 1950.0, B, L, Polarizer position, LST or EST. Events such as start and stop sampling, turn the receiver calibration on and off, can be programmed along the *P* coordinate. These events plus some additional parameters that define the scan are grouped together in a list called an event schedule (ES).

For manual control the *P* coordinate and the sample interval along the *P* coordinate are the only mandatory specifications. Events can be pre-programmed or inserted at the desired positions as the scan is in progress by issuing the necessary commands.

For computer control, however, a more complete set of scan specifications is required. The event schedule must also define the scan with a start and stop event, the value of the orthogonal (to *P*) coordinate and the scan rate. When the system is enabled at the beginning of a scan the computer will calculate a telescope target from the start event, scan rate and pre-sampling filter that is selected, such that when motion begins the telescope and filter will have a head start of 3 filter time-constants before the start coordinate is reached. The ME and telescope are slewed independently to this target and locked together in a 4 stage sequence that is tuned to strike a balance between rapid and smooth lock-ins.

If the event schedule also specified a polarizer position the computer will drive the polarizer to the correct angle (in the *P* coordinate system) while the telescope is slewing. In addition, the computer will control the focus position according to a pre-defined correction curve and the ZA of the telescope target. When the polarizer, focus and telescope systems are all ready the scan will begin at the specified rate and the data acquisition phase will honour each event as its position is reached.

While the scan is in progress the data acquisition phase monitors the position of the telescope in the *P* coordinate system by converting back from the current ME position. The control system works independently by keeping model of the demanded position in the *P* coordinate system which is converted forward every 3 sec to give the equivalent position in current equatorial coordinates. These values are interpolated every 1/6 sec and used to establish the demanded position for ME control.

The data that will be sampled at each sample point along the *P* coordinate and how it will be processed is specified by a second list called a sample list (SL). Each entry in the sample list will cause one quantity to be sampled or calculated at each sample point and put into a memory area which is later written onto the data tape. Discrete quantities such as coordinates are always available and are sampled immediately. Analog samples however must propagate through the pre-sampling filter and so the acquisition of these values by the *A/D* converter is delayed. Either the discrete or analog samples can be passed to a processing subroutine which returns a value that is put in the stream of data. The values that are returned from the processing subroutine can themselves be processed by other subroutines. In this way it is possible for example to pass the receiver output through a digital filter before using it for later stages of processing.

In addition each element of the sample list may have one quick-look (QL) subroutine appended to it. As soon as the corresponding entry is sampled or calculated it is passed to the QL subroutine where it can be processed or output. No result is returned for storage in the data stream. Although QL subroutines were originally designed to output immediate results for monitoring, they are often used for the bulk of data reduction where the results of a scan can be reduced to a few numbers and typed on the user's log sheet.

Once the sample list and event schedule have been defined the user can start observing. In order to move the scan, as defined by the event schedule, quickly from one source to another a catalogue mode was developed. In this mode the scan specifications are treated as positive or negative displacements from a catalogued position. A catalogue of up to 75 sources can be loaded from paper tape. When one source is selected by name its coordinates are added to the original ES to form a working version of the ES. In addition the system

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can be in the beamwidth mode whereby the events and the sampling interval are specified in beamwidth displacements. For example a calibration scan on a standard source might be specified as starting at $-3.0$ beamwidths and stopping at $+3.0$ beamwidths, with a sample interval of 0.10 beamwidths. Each time a scan is started the computer calculates the correct absolute displacement from the receiver frequency and applies a cos (delta) factor where necessary. As each scan is finished the original specifications are returned and can be reapplied to a new source.

Although only one ES can be active at one time the system has three event schedules. Each can be run singly or they can be activated automatically in a specific sequence or scan pattern. For example a series of 4 finding scans, 2 in RA and 2 in Dec, may precede a time scan on the peak of the source. All five can be run sequentially by specifying the correct scan pattern before enabling the system.

In some instances a sequence of commands may be repeated often or may be known well in advance. These commands can be pre-punched on paper tape, put into the teletype reader and used to command the system by switching to the reader mode.

One of the most important features of the ARO system is the ability to share software resources. A new observing sequence (sample lists and event schedules) can be generated in a matter of minutes by invoking a command that loads a two stage generator from the system tape. In the first phase the user is guided by a question and answer technique which sets up the sample lists and thereby generates calls for the processing subroutines that are required. In the second phase a linking-loader is brought into core which searches through the paper tape or system tape libraries. When all processing subroutines are loaded and the event schedules have been completed the user can preserve this combination as an observing module by dumping the core image on the system tape. He may later recall this module by name, modify the event schedule if necessary and dump the new version as another module. It is also possible to move modules from one system tape to another, that is users can share modules.

There are in effect three types of users with three learning levels in the ARO system. They are

a) the module user who learns how to use modules that someone else has generated and thereby needs to be familiar with only a subset of the full operational capabilities.
b) the module generator who can combine subroutines from the library along with scan specifications and observing procedures to create relatively simple or very complex observing modules.
c) the subroutine generator who can write his own processing subroutines which can again be very simple or can be complex enough to require a detailed knowledge of the monitor programs.

The leverage that can be obtained by sharing software is substantial and is improved by good documentation and communication amongst the users.

The 1969 data acquisition system is used by virtually all observers. Preliminary tests with the new control system indicate that it will enjoy the same popularity.

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