AUTOMATIC VLBI OBSERVING

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One of the principal specifications of a dedicated VLBI array will be that it be usable by a single investigator as though it were a single instrument. It should thus be controllable from a single point, it should accept a single set of instructions applicable to all telescopes and recording systems in the array, and it should require only the barest minimum of operator intervention at individual telescope locations.

It has been determined that the most economical and practical communication medium for telescope sky signals is magnetic tape. Although it is in principle possible to program all telescope functions in advance, possibly by mailed instructions for the local control computers, in practice it will undoubtedly be necessary frequently to issue immediate, ad hoc instructions in response to unanticipated events. Thus, a real-time communication medium will be needed between the control center and all stations. This should be a narrow-band system, for economy and flexibility. Experiments at the University of Illinois' Vermilion River Observatory (VRO) over the past several years demonstrate the feasibility of the concept and illustrate a possible mode of implementation.

Almost all observations at the Vermilion River Observatory (VRO) are done automatically, with no operator in attendance at the telescope. Continuum and spectrographic single-dish observations are almost invariably conducted in this way, generally using stored programs prepared in advance, but with capability freely to make immediate changes or ad hoc observations from a keyboard terminal at any location with access to the public telephone network. The observer may interrogate the telescope at any time to determine program status or to check such parameters as receiver system temperature, local-oscillator frequency, sidereal time, telescope pointing, etc., without interrupting the observing program. The observing program is automated to the degree that, for example, the telescope can be programmed periodically to go to a strong calibrator source, do hour-angle and declination scans, fit a two-dimensional gaussian to the data, and automatically correct its internal pointing-correction table.

For VLBI observations it has not yet been possible to dispense with continual operator presence because the available tape recorder only accommodates one-hour tapes. With four- or six-hour video recorders now available at extremely low prices, it should be possible easily to automate the recording function as well, at least for bandwidths of 4 MHz or less. The VLBI observing software and interfaces provide many monitoring functions to prevent operator blunders and undetected equipment malfunctions.

The VRO automatic VLBI observing system contains the following features. The TI960A control computer is fed a list of instructions specifying source parameters and VLBI setup parameters. At appropriate times, the telescope is automatically positioned on sources and instructions are printed out for the operator concerning tape changes and special procedures. A "warning board" of lights indicates the computer's monitoring of various quantities important to proper operation of a VLBI observation; at a glance, a "green board" shows all to be well, and a red light instantly calls attention to a neglected piece of equipment. While mistakes are still possible, this system minimizes the chances of many common errors which wreck VLBI experiments. A hard-copy observing log is generated detailing start and stop times, calibrations, and other important events.

The automatic observing list consists of card images which may be entered from the terminal keyboard, paper tape, or 9-track 800 BPI magnetic tape. A program in Urbana for the campus computer permits computer files or punched cards to be converted to 9-track or paper tape. A line editor program in the telescope computer allows modification of the observing list from the terminal keyboard at any time.

An observing list consists of control cards and source cards. Control cards produce sequencing control or messages to the operator. Source cards specify scans to be performed.

Control cards contain a control character in column 1, followed sometimes by a control parameter. These are:

T output message: TAPE CHANGE (beep) followed by (any text on the rest of the card)

S output message: STOP TAPE (beep) followed by (text on the rest of the card)

E end of list; exit from automatic mode and await further instructions

W HHMMSS wait until the prescribed U.T. before taking further action; the telescope may be moved by the operator as desired

e.g. W 133500 waits until $13^h35^m00^s$

When a list is read into memory, an N in column 1 indicates there are no more cards to be read.

A source card has V in column 1, followed by the following:

Columns	Quantity
3-6	Start U.T., HHMM (SS in columns 7-8 optional)
9-12	Stop U.T., HHMM (SS in columns 13-14 optional)
15-22	Source name, 8 alphanumeric characters
25-30	Source right ascension (1950), HHMMSS
33-38	Source declination (1950), DDMMSS
40	Polarization: L=left, R=right, S=special (message output)
41	Bandwidth: 0=2 MHz, 1=1 MHz, . . ., 5=62.5 KHz
45-53	Local Oscillator setting in Hz

It is the observer's responsibility to convert the desired sky frequency into an L.O. setting, depending on the I.F. chain in use.

For example, to observe W49 at 1665.401 MHz, followed by BL LAC as a filter calibrator and fringe finder:

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W 090000
V 0900  0920  W49 1665  190750  090100 R3    64487890
V 0920  0940  BL LAC    220039  420209 R3    64487890
V 0940  1000  BL LAC    220039  420209 R0    64487890
T
E
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This sequence observes W49 in right circular polarization with 250 KHz bandwidth until 092000; moves to BL LAC without changing the setup; at 094000 changes the bandwidth to 2 MHz; and at 100000 outputs the messages TAPE CHANGE and AUTO LIST ENDS. Stop times are adhered to scrupulously.

All of the following functions are automatic. At the beginning of each scan, the polarization, bandwidth, and L.O. are set. If necessary, the I.F. level going into the video converter is adjusted. The computer checks the L.O. setting (by reading a frequency counter), the video converter L.O. lock, the MARK IIC formatter conditions of 4 MHz lock, data, time, and pattern, and whether the IVC video tape recorder is actually in RECORD mode. If any of these conditions is not satisfied, the appropriate light on the warning board is turned to red. When all is ready, the system temperature is measured and printed on the log, along with the source name and actual start time.

During a scan, the computer continuously monitors the following, turning on warning lights and printing messages whenever trouble develops:

1. Telescope position and status -- being blown off position by strong winds, reaching hour angle limit, and so on
2. Analog I.F. chain: oscillator settings, phase locks, levels, and so on
3. Mark IIC terminal status: formatter condition and video recorder status

The only important run-time quantity not presently monitored is the head gap position of the IVC recorder. The immediate-playback output is decoded into a data stream with BOF's and EOF's detected. A warning light indicates missing BOF, but this is not currently sent to the computer. The decoded data are sent to an oscilloscope so the operator may observe and adjust the 60 Hz head synchronization signal from the formatter. The data may also be examined for frame count, pattern, and so on. It is not clear that an automatic system can be devised which will warn of improper recorder operation without crying wolf!

Other equipment failures may, of course, ruin an experiment; but we have conquered many of the common errors so that careless mistakes by a sleepy or distracted operator will be minimized.

It should be observed that this system has been implemented on a telescope that has been consistently under-funded, with no spare or backup equipment, with an obsolete computer with very limited (8K) memory and no high-level language compiler. That it has worked so well under these circumstances suggests that it should be perfectly feasible to automate an entire network via the public telephone system, given an engineering staff who are intimately familiar with VLBI operations and given a pragmatic rather than an idealistic design philosophy.

By means of conference calls, given proper organization at the telescopes, the entire array could be controlled in real time from a single location, conceivably anywhere in the USA, or even the world. Alternatively, schedules for automatic observing could be read into the memories of all the telescopes simultaneously.