RADIO ASTRONOMY OBSERVATORY
DEPARTMENT OF ASTRONOMY
THE UNIVERSITY OF MICHIGAN

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Memo to Dr. Robert Burns

From Hugh D. Aller

Re: Experience with Unattended Telescope Operation under Computer Control at Michigan

In 1977 the University of Michigan 26-meter telescope was placed under computer control and has been operating in an unattended, automatic mode since that time. The performance of this system has been excellent and has significantly exceeded our initial expectations. The system operates continuously, and during the past several years the telescope has been observing more than 80 percent of the time ( )7000 hours per year). The bulk of the "down time" has been for bad weather or telescope maintenance; after the initial checkout period, very little time has been lost due to control malfunctions. This memo describes some of the design ideas used in constructing the system and our experiences with it. At the end is a brief set of comments on specific ideas for the VLB array control system.

The observational programs at Michigan (at 4.8, 8.0 and 14.5 GHz) have primarily been involved with continuum polarization and flux-density measurements of discrete radio sources, although several mapping projects of extended regions have been carried out with the automated system. Because of the nature of the scientific programs and the fact that we are operating the telescope at or near its design limits, we place high emphasis on obtaining good pointing and accurate, repeatable measurements. The programs (involving different frequency/feed system combinations) are typically changed every one or two days; but some programs have run unattended for periods of three or more days. I developed the basic control program as a multi-level interrupt driven interpreter which accepts two character codes for such commands as scan, acquire, record data, etc. Control programs written in this interpretive language select the desired telescope motion during an observation, the operation of the polarimeters and radiometers, the recording of data etc.; these programs read in observing lists containing for each source the 1950 coordinates, the desired length of observation and any other needed information. In a typical program the source positions are precessed to the current date, telescope pointing corrections are applied (these corrections are updated periodically during the day from position scans of selected sources), and a preliminary reduction of the data is done in real time for quick look purposes. The preliminary results (fluxes and polarizations together with diagnostic data on radiometer and antenna gain and pointing) are printed at the telescope; and the raw, digitized data is stored on magnetic tape for later analyses at a remote computer.

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This computer control system is implemented using a (by current standards) modest system: a TI 980A minicomputer with 64Kb of memory, a TI 700 series terminal with cassette tape drives, four 8-inch (single density) floppy disk drives and several magnetic tape units. This system is interfaced to the telescope and radiometers through a digital system designed by Dr. T.V. Seling and built by the observatory staff which multiplexes the control functions for the telescope and radiometers into several parallel ports to the TI computer.

Of primary concern in the initial design of this system was the protection of the telescope from the effects of mechanical or control failure. A typical nightmare scenario is that the computer instructs the telescope to start slewing and then goes dead (for example because of a nearby lightning strike) so that it is unable to prevent the impending disaster. To prevent this type of situation our system uses a type of "dead man switch" to monitor the computer system: an external circuit requires a periodic signal from the computer or it turns the entire telescope off within several seconds. Electrical and mechanical interlocks are also used, and the control program itself contains several modules which do nothing but check the performance of the system. There are obvious checks such as refusing to observe objects below the horizon, but for un-attended operation, one must also check for such things as the failure of a slew motor. We fear software "bugs" almost as much as hardware failures, which is why all the basic telescope and data acquisition software is written into the computer monitor system where it is inaccessible to "users" or even to the observing control programs (which must operate through the interpreter). On a less serious level we found it necessary to incorporate a certain degree of "common sense" in the system to prevent, for example, the observing programs from deriving wild pointing corrections because of interference during a position scan. During the more than five years of automatic operation we have only had one potentially serious incident when a brake failed during a wind storm and the telescope was blown past a mechanical limit.

During our initial deliberations in the design of the control system, we considered several alternative possibilities, including controlling the telescope from the Michigan main-frame time-sharing computer system located 15 miles away. Even though we intended (at that time) to have an observer present at the telescope at all times, we rejected the idea of remote computer control primarily because of reliability considerations. Advantages of the remote computer concept were: a) it was already there with a proven operating system and the needed peripherals, b) program development would be much easier and faster, and c) someone else would be responsible for its maintenance. The disadvantages were: a) the avaliable data rates over telephone lines were too slow to support the needed transmissions to control the telescope motions in real time or to send the received data to the remote computer- thus an on-site computer would be needed in any case, b) the telescope would be dependent upon the reliable and continuous operation of the main computer, and c) the phone lines while generally good are occasionally subject to interference. Our experience during the past five years has confirmed the correctness of our decision. We <u>do</u> use the remote computer to develop observing control programs, construct source lists, and run simulations of telescope operations to avoid wasting telescope time because of timing problems; but aside from

transmitting programs and observing lists to the observatory by phone, the telescope runs independently.

I would strongly urge in the development of new telescope control systems that the goal be to make the operation automatic. Automatic operation should not be interpreted as inflexible operation, but rather it requires that the experimental procedures must be carefully evaluated in advance. We found that carefully evaluating what an experienced observer does at the telescope can lead to consistently higher quality data. My conclusion in developing our system was that the effort needed to develop an automatic system is the same order of magnitude as developing a "robust", user friendly system which must respond to the unpredictable input of an observer or operator. Of course the problems are quite different... it is rather difficult to impart much common sense to a computer program. The advantages of automatic operation extend well beyond the obvious savings in operating expenses. An important feature to us is that the computer controlled observations are consistent and repeatable- in a complex system such as the proposed VLB array this is perhaps even more important. An analogy can be made with the choice between an excellent typist using a manual typewriter and an average typist using a word processor: the first draft is far easier to produce with the good typist but the n-th revision of the document is produced much faster and more reliably by the word processor.

On the basis of our experience at Michigan, I would suggest the following as being the most reliable and effective control system for the VLB array. Each telescope would be equipped with an identical 16 or 32 bit mini-computer system of medium capacity. The capacity of these systems should be sufficient to permit independent operation and real-time evaluation of such parameters as pointing, system temperature, etc. which are needed to insure the early detection of equipment problems. Each control computer would be responsible for the independent operation of the associated telescope- including alerting local personnel concerning equipment malfunctions. The peripherals on these machines could be minimal... enough to run system diagnostics and to do a limited amount of program development. I would suggest that these control/reduction computers not be used as multiple user systems- to simplify the software and thus make it more reliable, and to minimize the possibilities of human induced system crashes. The central operating point of the VLB array would have an off-line computer which is identical (or larger but compatible) with the telescope control computers. This main system would be used for all program development and specification of observing lists etc. I would run the control computer network as a dictatorship with the central computer sending newly developed software over phone lines to the individual telescope control computers without depending on a person being there locally to do it. Local "improvements" would not be permitted! This arrangement is not merely to save money in reduced programing costs but more importantly to make the system more reliable and easier to update. Observing lists would be tested by telescope simulation programs at the central site and then be sent (again by phone connection) to the remote telescopes well in advance of the observing session. I believe that the system will be most reliable if the telescope control computers would operate in an asynchronous relationship with the central computer. Failure of any one system (including the main control computer)

would thus not result in the total destruction of an experiment. Also leased phone lines would not be needed, since communication between the computers could be done in short bursts several times a day or even less frequently. Based upon our experience I can see no justification for requiring a telescope control computer to be dependent upon frequent "real-time" instructions from some remote site.