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THE FLORIDA INSTITUTE OF TECHNOLOGY AUTOMATIC PHOTOMETRIC TELESCOPES

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I. INTRODUCTION

In recent years, the Fairborn Observatory in Arizona (Genet 1986; Genet *et al.*, 1987), the F.I.T. Observatory in Florida (Rafert and Oswalt 1987), and other earth-based observatories (Rafert and Markworth 1987; Smith *et al.* 1988), have been adapting mass-produced microcomputer technology to the full automation of small telescopes; the objective is to provide low-cost, high quality data to the largest number of science users. In this case, "fully automatic" means that the telescope, and indeed the entire observatory (multiple telescopes in a roll-off roof building), operates under computer control for weeks or months at a time without human intervention. An automatic observatory has been described (Boyd, Genet and Hall 1986; Genet *et al.*, 1987), which is located on Mt. Hopkins, in southern Arizona, and which is operated by the Automatic Photoelectric Telescope Service (APT Service), a service of Fairborn Observatory and the Smithsonian Institution. They, and others, are developing the capability to have the user, who may be located anywhere in the world, use a personal computer (PC) equipped with a modem to send observing program request files to the telescope site before the night begins, and retrieve data the next morning or later. This mode of operation is called "Remote-Access Automatic Photometry" (RAAP; Hayes *et al.* 1987). At the present time, major areas of activity within this framework include:

(1) Telescope automation. The present generation of small telescopes has validated the concept of autonomous operation of the telescope/observatory ensemble, and is rapidly spreading to users of small, relatively low-mass, special-purpose telescopes (generally, telescopes used exclusively for photometry). Several areas of further research are required: (a) application of this technology to larger, heavier telescopes using advanced mount models and artificial intelligence (AI) techniques, (b) generalization of the concept so as to allow a single automatic telescope to be used not only for photometry, but also for photopolarimetry, spectroscopy or imaging, and (c) advancement of the existing control techniques, such as centering algorithms, observational statistics as sky quality diagnostics, or multiple program priority scheduling algorithms.

(2) Global Network of Automatic Telescopes (GNAT). A global network of automatic telescopes has been proposed (Crawford, Genet and Hayes 1988; Baliunas, Cornell and Genet 1988) to link some of these distributed APTs and is under study by the Smithsonian Institution (Baliunas, 1988). At present, several groups including the Smithsonian, F.I.T. and JPL have plans to demonstrate the feasibility of linking several APTs, with the objective of demonstrating how this technique might be utilized in the course of an observational program to extend phase coverage, or safeguard time-critical observations against the possibility of inclement weather at one or more locations. The global network represents a natural extension of the capabilities of

individual APTs, and taken together with the use of interactive E-mail networks, has great promise to accelerate the rapid proliferation and applications of APTs of all types.

(3) Real-Time Remote Access Observing. The ability to obtain *real-time* status information from automatic telescopes with single channel photometers, and for the remote observer to interact and alter an executing program has yet to be demonstrated. An even more demanding application involves telescopes instrumented with CCDs.

(4) Small Astronomical Satellite (XSAT) Ground Support. A number of new, low-cost satellites are becoming available for use as astronomical observatories, e.g., XSAT-- Pegasus launched satellites such as those sponsored by CIT in Virginia). Opportunities also exist for astronomical observations to be made in space with larger instruments (i.e., IUE, HST, Space Station Freedom, the Great Observatories). We shall soon be witnessing a new era, in which complimentary ground and space based observational programs constitute the norm, rather than the exception. For example, it has recently been proposed that XSAT (Rafert and Speaker, 1989) be used for a small UV telescope, with a 9-month mission lifetime. This particular satellite is controlled by the user from a user-supplied ground station. Thus, it must function automatically for many orbits--similar to the situation confronting an earth-based automatic telescope which must function on its own for days or weeks. Ultimately, we envision a network of earth and space-based automatic telescopes, furnishing simultaneous observations across a range of passbands, extending phase coverage, and providing observations with a new degree of precision.

Several projects, described below, are currently underway here at F.I.T. to supply ground-based observational support for a variety of astronomy activities.

II. THE F.I.T. 0.41-m APT

We have a campus-based teaching observatory, which serves as a "garden" for new ideas and projects. Located off Dairy Road about a kilometer from campus are several small domes and support trailers. The largest dome, which was also acquired from surplus sources, houses a standard 0.41-m Cassegrain, equipped either with a Pacific Photometric Instruments DC Photometer, or a Starlight-1 Pulse Counting Photometer (manual change is required), and supported by a Cave mounting.

This particular telescope is being refurbished, and will acquire the old drive system which the 0.64-m had before we purchased the AutoScope hardware. This system is composed of:

a) Worm and Gear Drive. Both right ascension and declination axes have 221-tooth gears and matching bronze worms, which are driven by Superior Electric M0-92 frame size motors. A leaf coupler allows for some misalignment of the motor and gears, and eliminates binding.

b) Superior Electric IMD-002A driver cards. We use the 50 watt version.

c) Superior Electric IMD-015 microstep indexers. These cards allow selection of 5, 10 or 16 microsteps per full step (200 full steps per revolution of the motor). The indexers can be actuated either via a RS-232 interface card, or via pulse strings generated within the AT.

d) IOD-004A Interface Card. This is used to attach the Modulynx bus to our Tandy microcomputer.

e) Tandy 1000TX, with coprocessor. This is an inexpensive, 80286-based computer, with hard drive, modem, keyboard, monitor, and printer. We have configured the 1000 with both 5 1/4 and 3 1/2 inch drives.

f) Paddle. Pull-up resistors are used, so that when a button is depressed it pulls that bit of I/O to ground. Normal E-W, N-S, and slew move capability is provided, as well as additional paddle-functions for integrate and abort.

e) Metrabyte counter/timer board. Both the pulse trains used for the IMD-015, and the pulse input from the Starlight-1 (when it is attached) are routed via this card, employing the on-board counter/timers.

III. THE F.I.T. 0.64-m APT

Over the last four years, we have been developing a dark-sky observatory site here in Florida, with a 0.64-m automatic telescope for use by our students. A primary mission of our department is to expose our advanced undergraduate students and graduate students to research quality instrumentation. Although in principle it would have been possible to locate this facility anywhere, various other priorities exist which modulated our selection of location.

The heart of the 0.64-m is an unperforated 0.64-m mirror, which was obtained via surplus sources from the Air Force. As a historical note, this mirror was one of several used to take the first pictures of Sputnik, and was manufactured to a high optical tolerance. The optical configuration of the current telescope is that of a Newtonian, although the secondary has been motorized so as to be able to rotate to select one of four instruments which are located radially around the tube in "Newtonian" focus locations. At present, we have three main instruments for this telescope: (1) SSP-3A Solid State Photometer; (2) Thorn-EMI-Gencom Starlight-1R Pulse Counting Photometer; and (3) AutoScope CCD camera. Plans are underway to build a photographic film holder, as several of our students have interests in photography and this is an educational activity which can easily be accomplished during non-photometric periods of time.

We (Rafert and Oswalt, 1988) have constructed the telescope body, the mirror cell, the tube, and the mounting from locally procured material resources (i.e., "scrap" found in or near the campus machine shop). The telescope tube is a standard Cheverier truss, with support for the spider coming from one end ring, while the other end-ring is attached to a tub, which serves as a common point of attachment for the declination bearings, mirror cell, and several small power supplies. Both the tub and telescope mounting have been constructed from 3/8" aluminum stock, welded together to supply a rigid framework.

A fork-style mounting was chosen to simplify automatic operation. The polar axis is a 4" shaft, which is supported by two large pillow-block bearings; the declination movement is supported by two short 2" diameter shafts which rest in self-centering bearings. Both the declination axis and polar axis

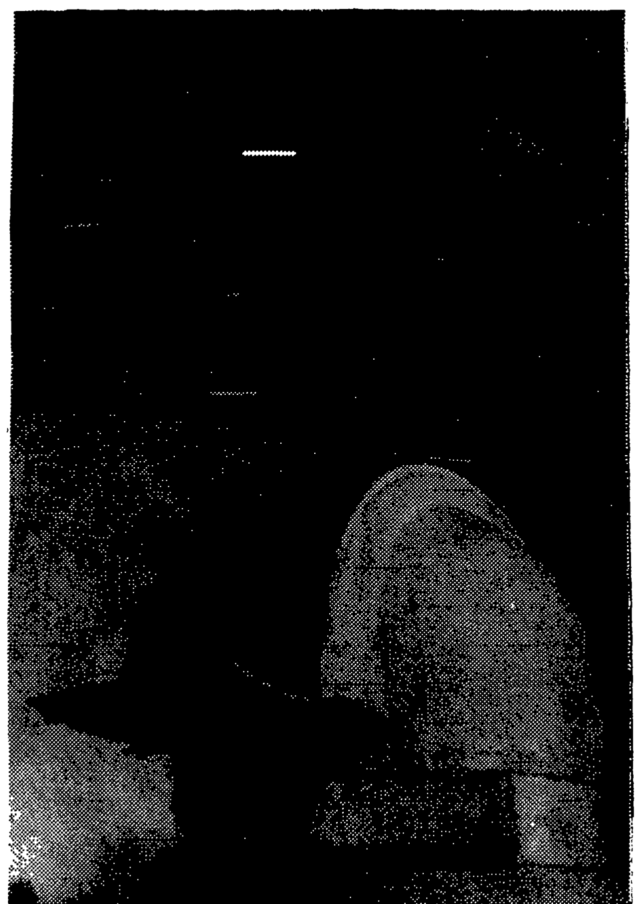

Figure 1. (right) The F.I.T. campus observatory dome which contains the 0.41-m telescope.

are supplied with 0.86-m diameter friction drive disks, manufactured from 3/8" aluminum. The telescope drive system contains no gears, and is composed of Berg and Pic belts and gears which ultimately serve to engage a 1-inch steel shaft which is tensioned against the 0.86-m roller on each axis. This telescope is shown in Figure 2.

The observatory is located in the Bull Creek Wildlife Refuge, a 22,006 acre refuge under the management of the St. John's River Water Management Authority. Located about 25 miles west of Melbourne, the skies at the site are as dark as can be found in Florida. The area is within a stringently restricted wildlife and water control area that is unlikely to suffer encroachment of construction development and associated light pollution for well beyond the duration of the permit. F.I.T. has been granted a lease on five acres of property within the refuge for a period of 20 years. We have installed a new 18-foot AshDome, shown in Figure 3, complete with site work and 10-foot dome wall, so as to raise the dome opening to about 16 feet above the ambient level (75 feet above sea-level). Telephone and power are supplied from an adjacent state-operated facility.

The telescope control system consists of:

(a) AutoScope AT-interface card. This card supplies the AT-to-stepper driver interface, and requires a full XT/AT slot. The card is compatible with ATIS, and has a variety of inputs and outputs for devices such as limit switches and paddles.

(b) Limit Switches. We use Schmidt-trigger type detectors, which have a very high positional accuracy and repeatability. Two switches will be supplied per telescope axis. These switches are "hard wired" to the telescope controller, and do not rely on software to prohibit the movement of the telescope into forbidden zones. A variety of other safety/emergency switches will be supplied as well.

(c) Paddle. Our design allows the operator to select a variety of speeds/directions, and to use the paddle as a remote programming device for the computer during real-time operations. Normal functions such as integrate, cancel integration, etc. are also supplied. All functions are accomplished by grounding pull-ups, so that only low voltage DC power is routed through the paddle.

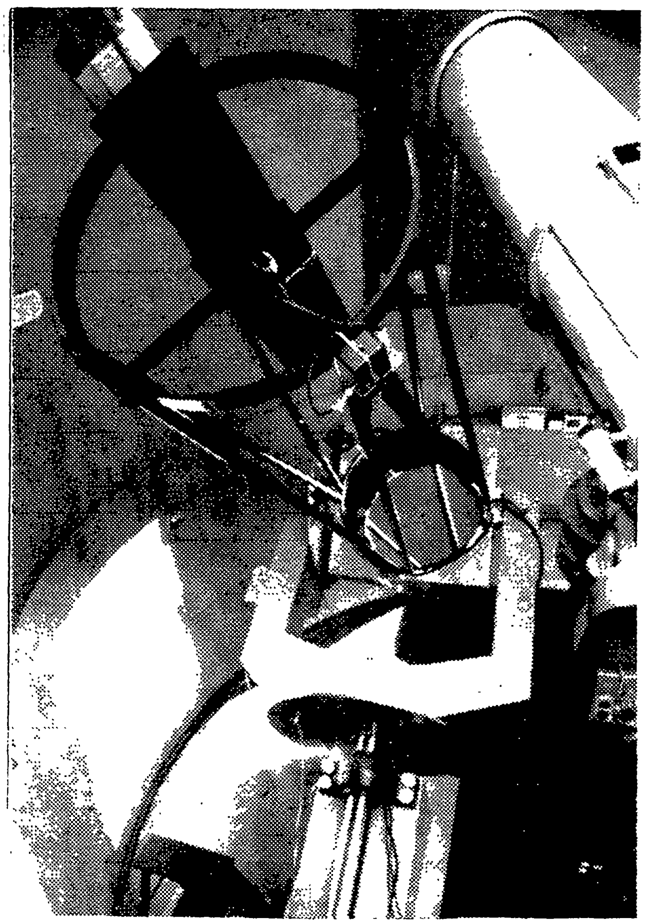

Figure 2. (right) The F.I.T. 0.64-m telescope. The telescope is shown with a special-purpose image intensifier/video system attached during optical and mechanical performance trials at the campus observatory. The instrument is at the Bull Creek dark-sky site.

(d) Stepper motor drivers. We use the AutoScope/Measurematic drivers. These cards will accept the digital outputs from the AutoScope interface card, which supplies a pulse rate and direction signal for each axis.

(e) Stepper motors. A common topic of discussion regards the issue of using either stepper motors or incremental torque motors (encoded DC motors). Although we have had experience with both types (use of steppers on 0.36-m, 0.41-m 0.46-m, 0.64-m and 1.04-m telescopes; use of torque motors on 0.9-m Boller and Chivens), we see no particular discriminator which biases the decision in either direction, and view the two types of motors as functionally identical. We have selected the steppers on the basis of compatibility with other systems (and other GNAT users as well). It should be noted however, that DC units driven by cards manufactured by Galil are plug-replacement compatible with either the Measurematic or Superior Electric cards (with limited TTL logic on the Autoscope board prototype area).

(f) Photometer control. We use the Optec card.

(g) Software. The amount of time and expense that is associated with software development is almost always underestimated! We use ATISSCOPE, a commercially available program for AutoScope Corporation as our software core. This program has published source code which is easily modified (Turbo Pascal); it is used by all members of the GNAT; it runs all of the components listed above and those below which are presently not in use by any automatic telescope system. No doubt, we too are underestimating the software development effort that will be required--but are nonetheless taking steps to minimize that activity and to not "reinvent the wheel". Major software additions will deal with mount modeling, backlash compensation, detection and cancellation of drive periodicities, and special purpose application software.

(h) Power supplies. Appropriate supplies will be furnished for each item above.

(i) Uninterruptible Power Supply. Because of the nature of automatic telescopes, provision must be made to shut down the system, and close the dome rapidly under certain conditions, such as the onset of high winds, electrical storms, humidity, dust, or substantial power fluctuations. These conditions are often associated with interruptions of power. Even a small glitch can "crash" a computer. We plan to purchase one of the Sola UPS of proper size to supply at least 10 minutes of full power to the system.

(j) Encoders. The present APT technology runs "open loop". Although this is adequate for most applications, we intend to eventually develop feedback capability via optical position encoders, and to apply AI techniques to the telescope so that it can learn from its "mistakes", as well as its "successes". We plan a staged development sequence in this area. Until now, most APT's have been built to run open-loop, without encoders which typically add an order of magnitude to the computational burden of operating the telescope. Now, the increase in computational ability which can be supplied in the dome, makes it possible to service all of the telescope functions, and to close the loop of the mechanical (pointing) system as well.

(k) Computer(s). A 80286 clone is used.

(l) The Observatory Controller. The observatory controller supplies more system I/O than is normally available in a standard PC. We use the AutoScope Observatory Controller (Genet, 1989) not only as it possesses all of the necessary I/O functions, but as it is fully compatible with the telescope controller interface (minimize software). The observatory controller will be connected to the following items: *i) Weather Station* (Hinds International); *ii) Cloud and precipitation sensors* (Vaisla precipitation detector; Fairborn cloud sensor); *iii) Clock* (Heath); *iv) Dome Control.* Control of the AshDome AC motors will be by digital relay, following the design used at the SFASU 1.04-m telescope (Rafert and Markworth, 1985); *v) Safety.* The observatory controller will also be used to monitor zone intrusion alarms (Radio Shack motion detectors aimed away from the telescope), and to activate a warning siren for either intrusion or an emergency situation.

(m) The CCD Camera. We have purchased an off-the-shelf cryogenically cooled CCD system. This unit will serve as a stand-alone CCD controller working in harmony with the telescope and observatory.

IV. FUTURE DIRECTIONS

(1) Remote Access Automatic Telescopes. Originally proposed by Hayes (1987), remote access automatic telescopes differ from earlier concepts of remote access observing, in that there is no need for an on-site observer whatsoever. This type of observing is a natural extension of the capabilities of an automatic telescope, and the first steps in this direction are presently being taken by members of the Southeastern Association for Research in Astronomy (SARA). This consortium, which consists of F.I.T., East Tennessee State University, the University of Georgia, and Valdosta State College, is developing a one-meter class APT telescope for a prime astronomical site in Arizona. The instrument will be accessible to each member via national computer networks and will initially provide remote CCD imaging and photometry capability. Once the concept is proven and reliability and safety margins have been set and achieved for small telescopes, the concept will most likely be extended to larger telescopes. If this can be accomplished, the impact to the astronomical community as a whole will be great, as many additional astronomers will be able to participate in projects requiring large telescopes-- participants who are effectively denied access to these large instruments by virtue of working at small universities with small travel budgets, and/or heavy teaching loads. There also exist some exciting educational aspects for the entire community, *e.g.*, remotely obtaining a spectrum in real time with a large telescope at a national observatory while your astronomy class participates.

(2) Global Network of Automatic Telescopes. In global networks (Crawford, Genet, Hayes, 1988; Baliunas, Cornell and Genet, 1988; Baliunas, 1989) many telescopes are distributed in longitude, and latitude as well. The reason for doing so in longitude involves the diurnal cycle; the reasons for doing so in latitude include different weather patterns at similar longitudes, different hemispheres, and duplicity of simultaneous or time-critical observations. Many new observational

Figure 3. The observatory compound at Bull Creek.

programs that require coordination of many observatory sites, which although in theory are possible now, will likely ensue as the sheer level of effort required is distributed and institutionalized in software. This coordination might take the form of continuous observations of particular objects; or mixed mode observations involving simultaneous spectroscopy and photometry; it might well also involve simultaneous or complimentary space-based observations. We have two activities in this area: (1) linkage of our telescopes in Florida, not just with each other, but with the SARA telescope in Arizona, and (2) demonstration of a capability to track and image space objects, using telescopes distributed from Florida to Hawaii, using advanced hyperspectral imaging spectrometers (Phillips et al, 1990).

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