

THE UNIVERSITY TELESCOPE AND OBSERVATORY

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Birmingham University operates a computer controlled 0.4 m telescope for teaching purposes. The telescope, its control system and suite of instruments are described. Pointing accuracy of the telescope has been determined to be better than 7 arc seconds rms.

1. INTRODUCTION

The University Observatory was established in 1982 primarily to provide a facility for optical observations by students on the Physics with Astrophysics undergraduate B.Sc. course. The intention was to provide a system which would allow students to make efficient use of the limited occurrence of clear dark skies, and for this reason the decision was made to use computer control of the telescope pointing and tracking.

In many small observatories much time is wasted trying to find the object of interest by comparing the view through the telescope with that of a photograph or finder chart. The aim, therefore, was to eliminate this by accurate pointing.

The observatory houses a conventional equatorially mounted 0.4 m Newtonian/Cassegrain telescope, both the motion of the telescope and the dome being controlled by a PDP 11-34 computer.

Observations are made using a variety of instruments including grating spectrographs and a UVB photometer. Each year students also design and build their own instruments to be used on the telescope. The telescope is used for 2nd year project work, a 3rd year Observatory Laboratory and during a 3rd year Group Study.

2. THE BUILDING

The observatory consists of a two-storey building which houses the telescope, control room, dark room and laboratory/rest area. The telescope is supported by North and South concrete piers which are independent of the rest of the building and are tied at the first floor level. The decision to have the telescope at first floor level was made to avoid thermal effects close to the ground and for security reasons. The base of the dome is at a height of 4.5 m above the ground making access difficult to vandals.

The dome is an aluminised steel structure 4.5 m in diameter (Ash-Dome) which has electrical opening and rotation. The dome position is measured using a 9-bit optical encoder which is directly geared to the dome drive motor. The dome encoder reads the position with a resolution of 0.9 deg and the computer positions the dome to an accuracy of about 2 degrees. This is adequate as the dome aperture is large (1.28 m) compared with that of the telescope (0.4 m).

3. THE TELESCOPE

The basic instrument – optics, mounting and worm wheel drive – was purchased from Astronomical Equipment Ltd. Luton, Bedfordshire. The encoding, drive and control system was designed and built in the University.

The mounting is an English cross-axis system with a counter-balanced declination axis (see Fig. 1). Each axis is driven by a worm and wheel arrangement. The worm wheel has 720 teeth so that one revolution of the worm moves the telescope 0.05

deg on the sky. One end of the worm is driven by a DC torque motor whilst a 15-bit optical encoder at the other end provides a readout of the angular position, the least significant bit (LSB) of the encoder corresponding to 0.5 arcsec. Since this encoder only measures the position of the telescope within one revolution of the worm (0.5 deg) it is necessary to find the coarse position of the telescope to determine which revolution of the fine encoder is being read. To achieve this, a coarse resolution (11-bit) encoder is coupled directly to the right ascension axis. In the case of the declination axis the encoder is geared 1:1 to the axis as the end of this axis is not accessible. The coarse encoder

Fig. 1. A general view of the observatory.

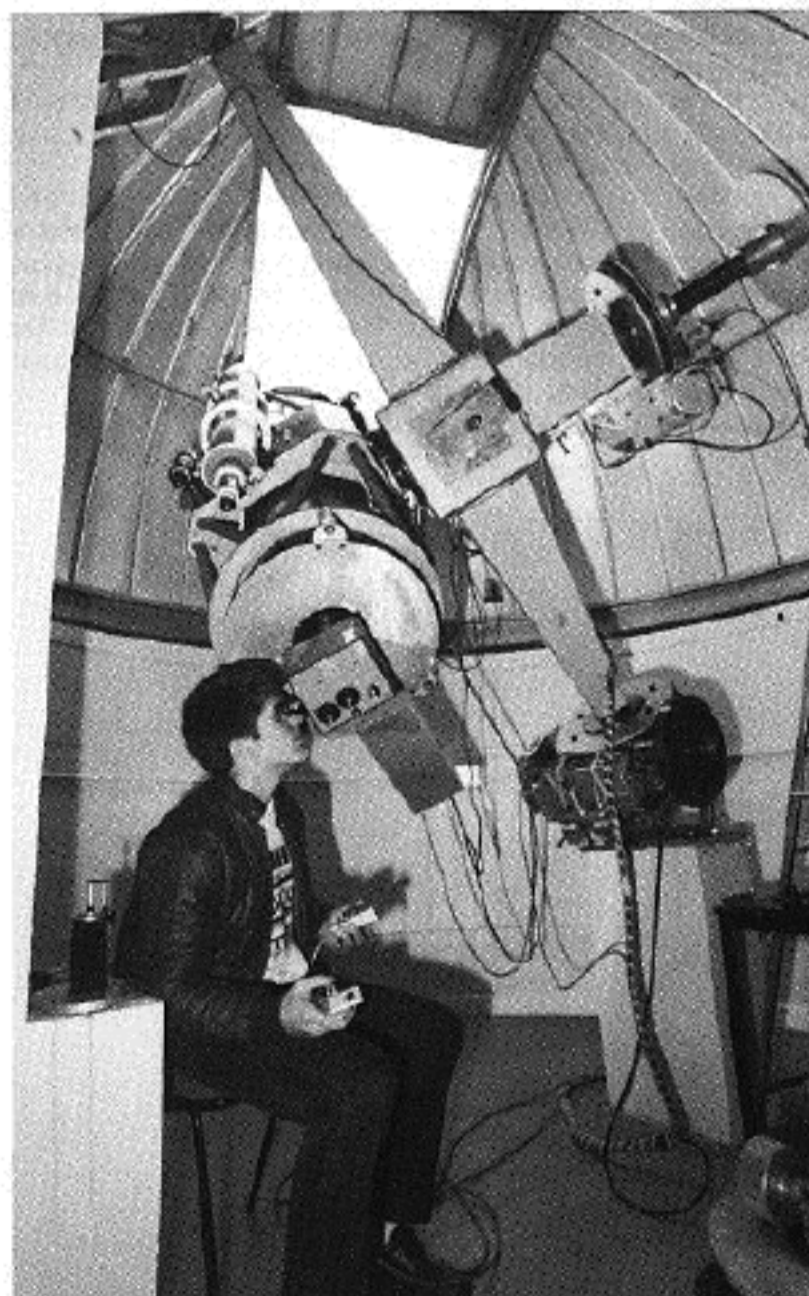




Fig. 2. Halley's comet.

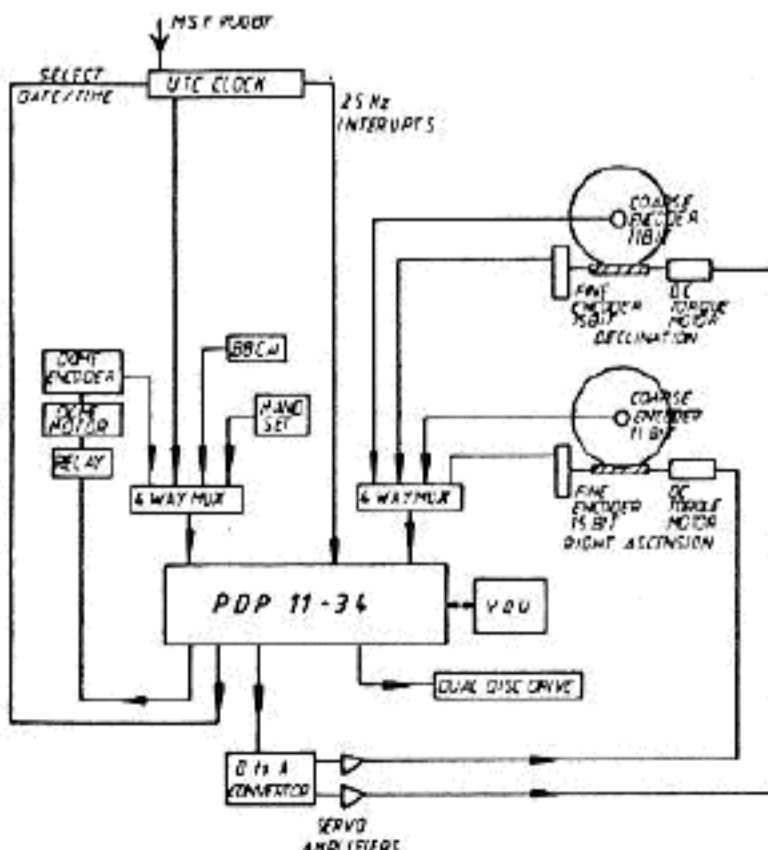
has a resolution (LSB) of 0.175 deg, which is high enough to unambiguously determine the revolution number of the fine encoder. This combination of fine and coarse encoders enables the positions of the axes to be read unambiguously with a resolution of 0.05 arcsec, a resolution of this order being required in order to permit satisfactory determination of the velocity of the axes for the pointing control software (see Section 5). The absolute accuracy of the readout is of course significantly lower since it depends on the accuracy of the worm and wheel as well as that of the fine encoder, and is \sim few arcsec (see Section 7).

4. OPTICS

The telescope is a classical Newtonian (f5) or Cassegrain (f20) system. The Newtonian focus is only used for direct photography and has a field size of 61 x 41 arcmin when used with a 35 mm camera. Figure 2 shows an unguided 2 min exposure of Halley's comet taken in 1985.

The 408 mm primary mirror is of Zerodur glass ceramic and is figured to 1/20th wave. The Cassegrain system uses a motor driven secondary allowing a large movement of the focal plane behind the perforated primary. Most instruments are used at the Cassegrain focus. The floor level was chosen so that for most observing positions the instrument is accessible without the need for ladders.

Fig. 3. Telescope Control system block diagram.



An intensified TV system is used for acquisition. It consists of a Mullard XX1500TV image intensifier with a gain of 45000, optically coupled to a Hitachi Newvicom Camera. The camera is placed behind the primary mirror and can intercept the f20 focal plane by the insertion of a motor actuated plane mirror. When the grating spectrograph is used, the mirror is driven out and the slit and reflected star image can be viewed via an auxiliary mirror and re-imaging lens. In this way a star can be guided on the spectrograph slit whilst taking a spectrum. Under dark conditions the intensified camera can detect stars as faint as 15th magnitude without any integration.

5. THE TELESCOPE CONTROL SYSTEM

Control of the telescope is based on a PDP 11-34 computer. A block diagram of the overall control system appears in Fig. 3.

A radio clock (European Electronic Systems type RC060C) receives coded time signals transmitted by MSF Rugby on 60 kHz and provides UTC date and time with a resolution of 1 s together with 125 Hz square wave pulses in phase with UTC. These are divided down to generate 25 Hz interrupts to the computer which initiate the synchronous loop of the pointing control program. Each interrupt cycle the computer reads the positions of the coarse and fine encoders on each axis via an i/o port and a 4-way multiplexer. The fine and coarse readings are then combined to determine the position of each axis and by taking the difference between the new value for the position and the value on the previous cycle the velocity is also derived. The resolution of the position readout is such that estimates for the velocity of the axes can be derived which are sufficiently free of quantisation noise for pointing control loop stability. By taking the difference between the measured and desired positions for each axis a position error is determined and this, together with the velocity information, is used to derive an 8-bit value representing the torque demand for each motor. These values are written into output registers and a D to A converter followed by a servo amplifier drives each motor. On each cycle of the synchronous loop the computer also reads the UTC clock via another i/o register and 4-way multiplexer. The position demand for the RA axis is then updated so that this axis is normally driven at the sidereal rate. A handset is interrogated in each cycle and depending on which buttons are depressed corrections may be made to the position demands for either axis to provide motion at either the guide or set rates (see Section 6.1). It is also possible to use the telescope to track rapidly moving objects such as Earth satellites (see Section 6.2).

After completing execution of the code in the synchronous loop, control is then returned to the background task - the asynchronous loop. The asynchronous loop provides communication with the operator via the VDU and provides overall control of the mode of operation of the telescope (e.g. slewing of new target, tracking, etc.). Depending of the option selected (see Section 6) it also performs tasks such as calculating position demands from the mean place of an object and correcting the position for the effects of refraction in the atmosphere and for the geometrical pointing parameters of the telescope. The asynchronous loop also reads the optical encoder which measures the dome position and controls the dome motor via relays.

6. TELESCOPE CONTROL FACILITIES

The interaction between the observer and the control program is by a menu which is displayed on the VDU. The following options are available.

6.1 Normal Menu Operation

1: Slew to zenith

The telescope is slewed to point to the zenith and halted. This is the position in which the telescope is normally parked when not in use.

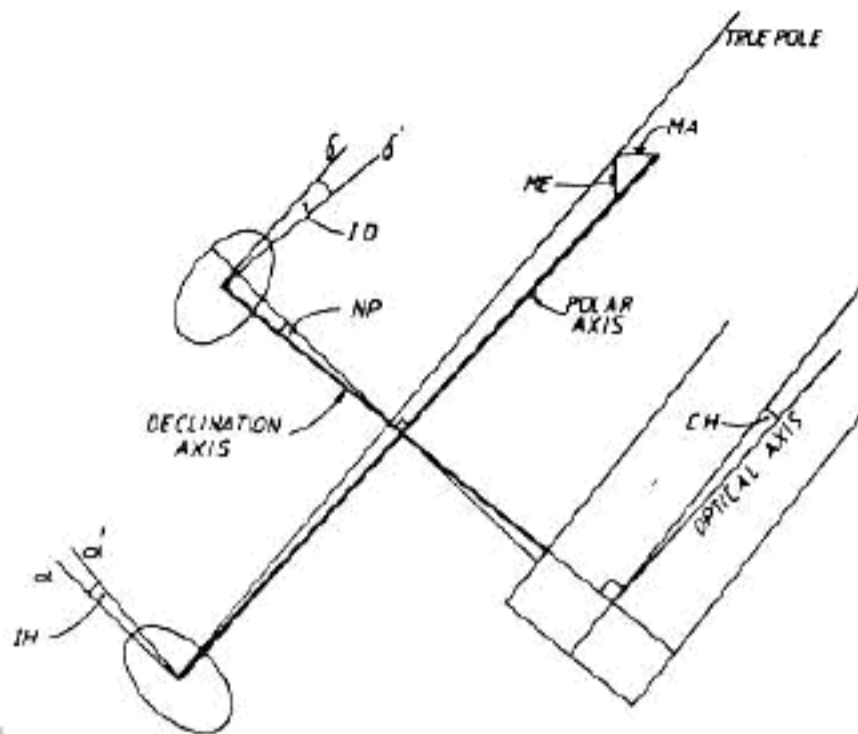


Fig. 4. Geometric pointing parameters of the telescope.

- 2: Slew to access
In this case the telescope is driven to a position due south with the telescope at an fixed elevation of about 10 degrees. This allows convenient access to the mirror covers and dust caps on the finder telescopes.
- 3: Enter new object
The observer is prompted for the mean place, i.e. catalogue position, of the desired object in RA and Dec and for the equinox of the position. The apparent place is then calculated by applying corrections for precession, nutation and aberration. Finally corrections are made for refraction in the atmosphere and for the six geometrical pointing parameters of the telescope (Fig. 4). The telescope is slewed to the position and the object is then tracked at the sidereal rate.
- 4: Return to last object
- 5: Change guide and set rates
If we wish to make small changes to the demanded position of the telescope these can be achieved by pressing the 'guide' or 'set' buttons. These switches are polled by the computer in the 25 Hz synchronous loop. Offsets are added to the position demands depending on how long the switch was closed and the value to which the corresponding rate has been set. In the start-up part of the programme a parameter file is read which contains the nominal values of 10 arcsec/sec and 100 arcsec/sec respectively for the guide and set rates. If these values are not suitable they can be changed under option 5.
- 6: Search data file for next object
The observer is prompted for a name of an object, which can be any alphanumeric name of up to 10 characters. A disk file is then searched for the named object and the position is returned whereupon the telescope slews to and then tracks the object. The coordinates of several hundred stars from the bright star catalogue are held on disk and are referred to by name e.g. Alpha-Lyr.
- 7: Change offsets
This allows the operator to change the two pointing

parameters [H and ID which are the index errors of the RA and Dec encoders. These values change with time because of temperature effects in the meshing of the worm and wheel. They can also be used to account for various nominated optical axes of different instruments.

- 8: Enter trail amplitude

It is usual when obtaining slit spectra of stars to widen the spectra by moving the star along the slit at right angles to the dispersion. This is achieved by trailing the star by a triangular ramp in RA. This option allows the amplitude of the trail to be set up. A typical value is 25 arcsec which widens the spectrum to 1 mm.

- 9: End of observing session.

6.2 Other Tracking Modes

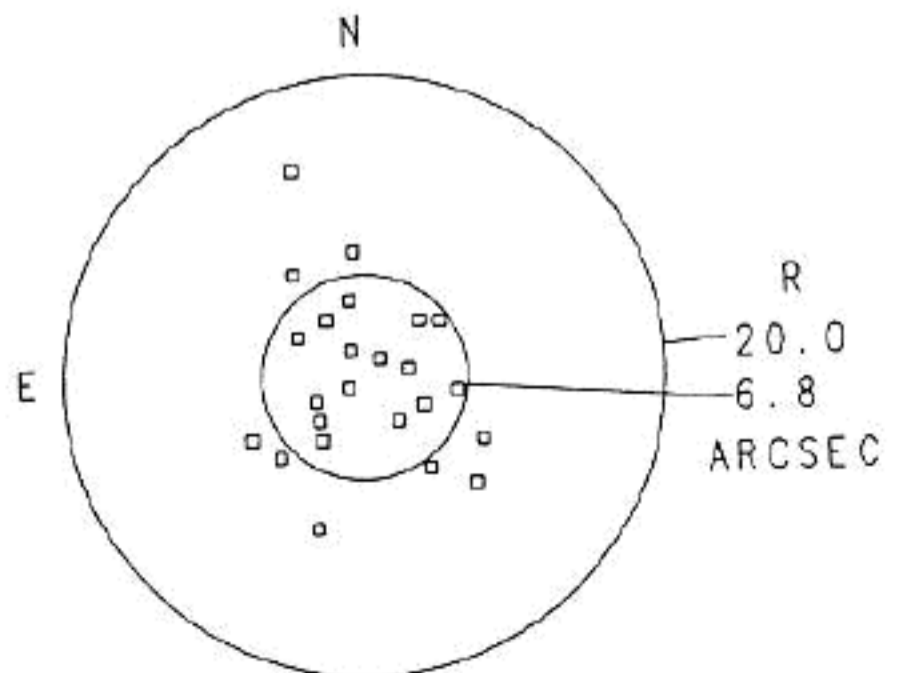
In addition to the normal slewing and sidereal tracking rates the telescope can be driven in three other modes.

- 1: Trailing - see option 8 above
- 2: Differential rates
This provides a fixed angular rate on the sky, independent of RA and Dec. This rate is specified in radians per interrupt (25 Hz) relative to the sidereal rate. The values are read from the parameter file. This mode is useful for tracking slowly moving non-stellar objects such as comets, asteroids, etc.
- 3: Satellite tracking mode
An interface is provided to allow a BBC microcomputer to continually change demanded offsets at the 25 Hz rate. This allows the tracking of a fast moving object such as an Earth satellite or the Space Shuttle.

There are not enough inputs to the PDP to allow dedicated switches to enable these extra facilities so that use is made of the keyboard buffer of the VDU. To enable trailing, differential tracking or BBC control of the telescope the characters T D or B are entered via the keyboard.

In addition to polling the 'guide' and 'set' buttons at the interrupt rate the computer also interrogates a 'stop' button which, when depressed, causes interrupts to be disabled thus halting the telescope and dome and returning control to the menu.

Fig. 5. Results of pointing tests.



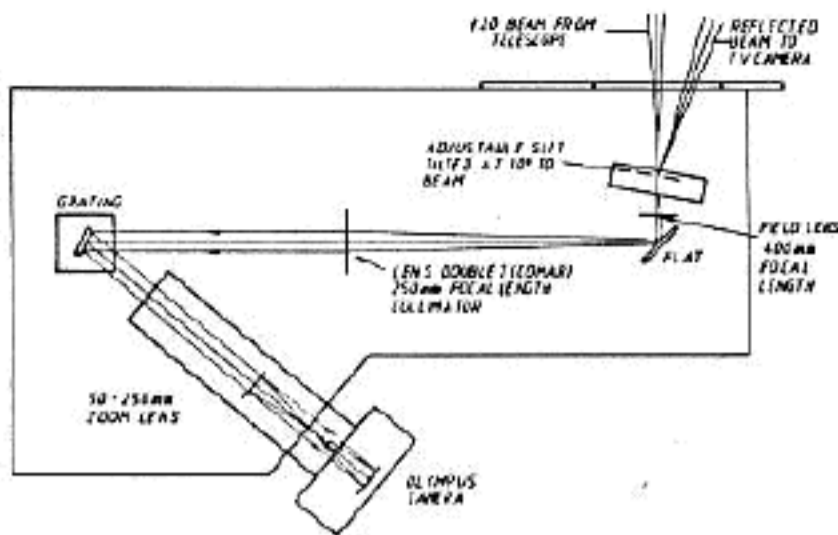


Fig. 6. Schematic diagram of the Medium Dispersion Spectrograph.

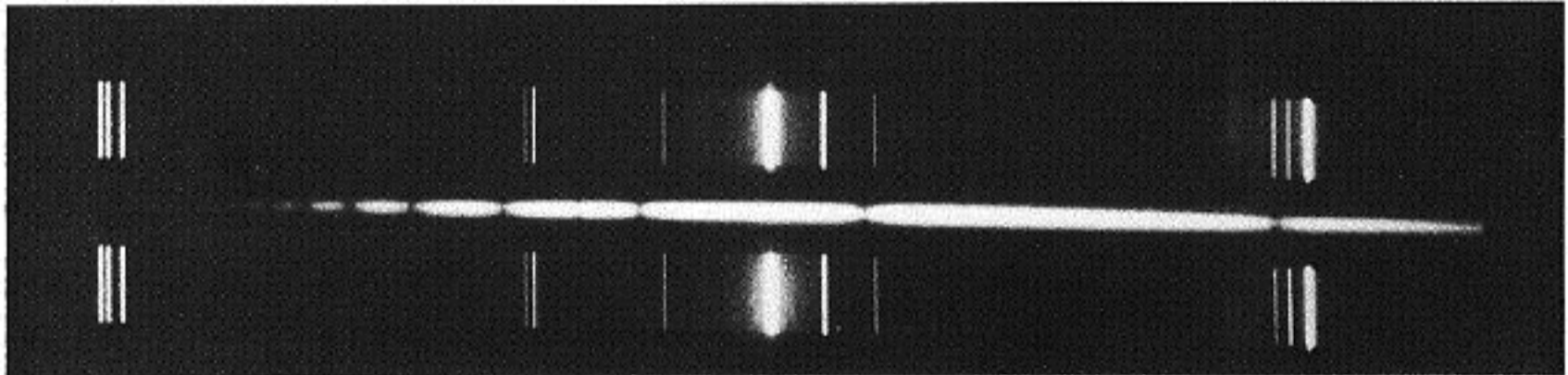


Fig. 7. High Dispersion Spectrum of the star Zeta Ursa Majoris.

7. TELESCOPE POINTING ACCURACY

The six geometric pointing parameters (see Fig. 4) and a number of flexure terms are determined by means of a pointing test. This consists of demanding the telescope to acquire a series of stars whose positions are taken from a catalogue. Each star is manually centred in the field of the main telescope and the raw encoder positions (corresponding to Hour Angle and Declination) and Sidereal Time are recorded. The raw positions are compared with the apparent places (calculated from the catalogue positions of the stars) using a program called TPOINT provided by P. T. Wallace. This program provides estimates of the six geometrical parameters and other pointing terms. The values thus determined are then manually entered into a parameter file which is read by the pointing control program each time it is initialised. An analysis of a pointing test is shown in Fig. 5 which indicates an rms pointing error of 6.8 arcsec – a typical value. The values for the pointing parameters are shown in Table 1. The only parameter which we consider to be excessive is the non-perpendicularity of the polar and declination axes. The value of 629 arcsecs is rather large and if possible we propose adjusting the bearings.

Table 1: Telescope Pointing Parameters.

Coefficient	Value (arcsec)	Standard Dev
IH	-3748.2	28.6
ID	820.1	9.5
NP	629.8	9.4
Ch	-405.7	28.1
ME	-77.1	7.0
MA	75.7	2.8

8. INSTRUMENTATION

Apart from direct photography we have the following instrumentation:

- U B V Starlight 1 Photometer (EMI-GENCOM)
- Low dispersion spectrograph (LDS)

(c) Medium dispersion spectrograph (MDS)

The photometer is a commercial unit manufactured by EMI-GENCOM which uses a very low dark count photomultiplier and comes equipped with photon counting electronics which we have interfaced to a BBC microcomputer. This works very well indeed but is used infrequently for conventional photometry as stable photometric conditions are uncommon in the UK.

The low dispersion spectrograph consists of a blazed transmission grating of 300 lines/mm placed in the converging f20 beam. The dispersion is altered by varying the separation of the grating and the detector (at present a photographic emulsion). Very low resolution ($R < 300$) spectra of stars and objects of small angular size can be obtained in very short exposures with this device.

The medium dispersion spectrograph is a conventional grating spectrograph with a novel feature. This is the use of a

zoom lens in the camera (see Fig. 6). The refocussing lens has a focal range of 50-250 mm allowing adjustment by a factor of 5 in linear dispersion with a single reflection grating. Three gratings are available (1200, 300 and 150 grooves/mm) giving an overall range of reciprocal dispersions of 33A/mm to 1280 A/mm. Figure 7 is a high dispersion spectrum (33A/mm) of the star Zeta UMa obtained with the MDS showing the Hydrogen Balmer absorption lines in the stellar spectrum and on either side calibration lines of Zn, Cd and Hg. At present the spectrograph uses photographic film as a detector and is limited to relatively bright objects, but we have purchased a CCD device which we expect to install on the spectrograph in due course.

9. CONCLUSIONS

Since it was commissioned in 1983 the telescope has operated reliably apart from a couple of relatively minor hardware problems with the computer. The rms pointing error of 6.8 arcsec is regarded as very satisfactory. The pointing accuracy is at present limited by backlash in the gear drives but the ability to point automatically with a precision of about 10 arcsec means that objects can be easily acquired even during daytime when they may not be visible. In fact a recent student project successfully observed infrared sources during daylight.

To date the observatory has only been used for student teaching, however we may in future use it for making observations of the optical counterparts of X-ray sources. In order to do this in the most efficient manner possible we are at present looking into the feasibility of fully automating the operation of the telescope – with automatic opening and closing of the dome and an automatic data acquisition system.

ACKNOWLEDGEMENTS

Many of the astronomical programs used in the pointing of the telescope and all of the programs involved in pointing test analysis were provided by P. T. Wallace of the Rutherford Appleton Laboratory. We wish to thank him for these programs and for other help and encouragement given during the development of the telescope control program.