Aspects of an Integrated Telescope Computer System

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INTRODUCTION

The art of computing was early recognized by astronomers as being the link between observation and theory. Computing became more and more important with the appearance of electronic computers.

Today we can regard the application of electronic computers in three different aspects.

1. Theoretical investigations.
2. Data handling, that means collecting of astronomical observations and reduction to observational results.
3. Control of telescopes and other astronomical instruments.

The present paper deals with item No. 3 only. It should, however, be emphasized that the combination of items 2 and 3 will lead to fully automatic astronomical observation in the future.

Although the planning of the development of a computer-controlled large telescope is regarded here in a quite general aspect, the ideas behind are often correlated with the ESO 3.6-metre telescope and its specific layout. The principal idea is that a medium-size process computer forms the central unit of the system and that a few small computers for special tasks are interfaced with the main computer into a time sharing system. Some tasks may also be more conveniently carried out by special hardware units, rather than by a general purpose computer.

Figure 1 gives a general description of the telescope and summarizes the different tasks which are described in this paper.

SETTING THE TELESCOPE TO THE ASTRONOMICAL OBJECT (Figs. 2 and 3)

It has been a common working mode among astronomers to have their program stars on cards. This gives a convenient way of selecting the stars one wants to observe on a specific night. Paper tape is inconvenient unless one has just one night's program properly arranged on the tape. Magnetic tape would make it easier, but the very best way seems to be to use fast external storage, *e.g.* a magnetic disk. Storing the observers' files or even whole catalogues directly in the core memory would take too much space. There are reasonable disk units with capacities in the range of 2–3 million 16-bit words. On such a disk pack several astronomers could have their own files and the disks can be easily exchanged. Maximum access times are less than 200 msec.

In general the astronomical objects or program catalogues will be stored with coordinates for a standard equinox. These coordinates must then be corrected for precession, proper motion, aberration, refraction and telescope flexure. These corrections depend upon the time of observation, the coordinates of the object, the east or west position of the instrument, and the meteorological conditions. One part of the corrections can be determined in the computer by well known astronomical relations, others must be found empirically by observations.

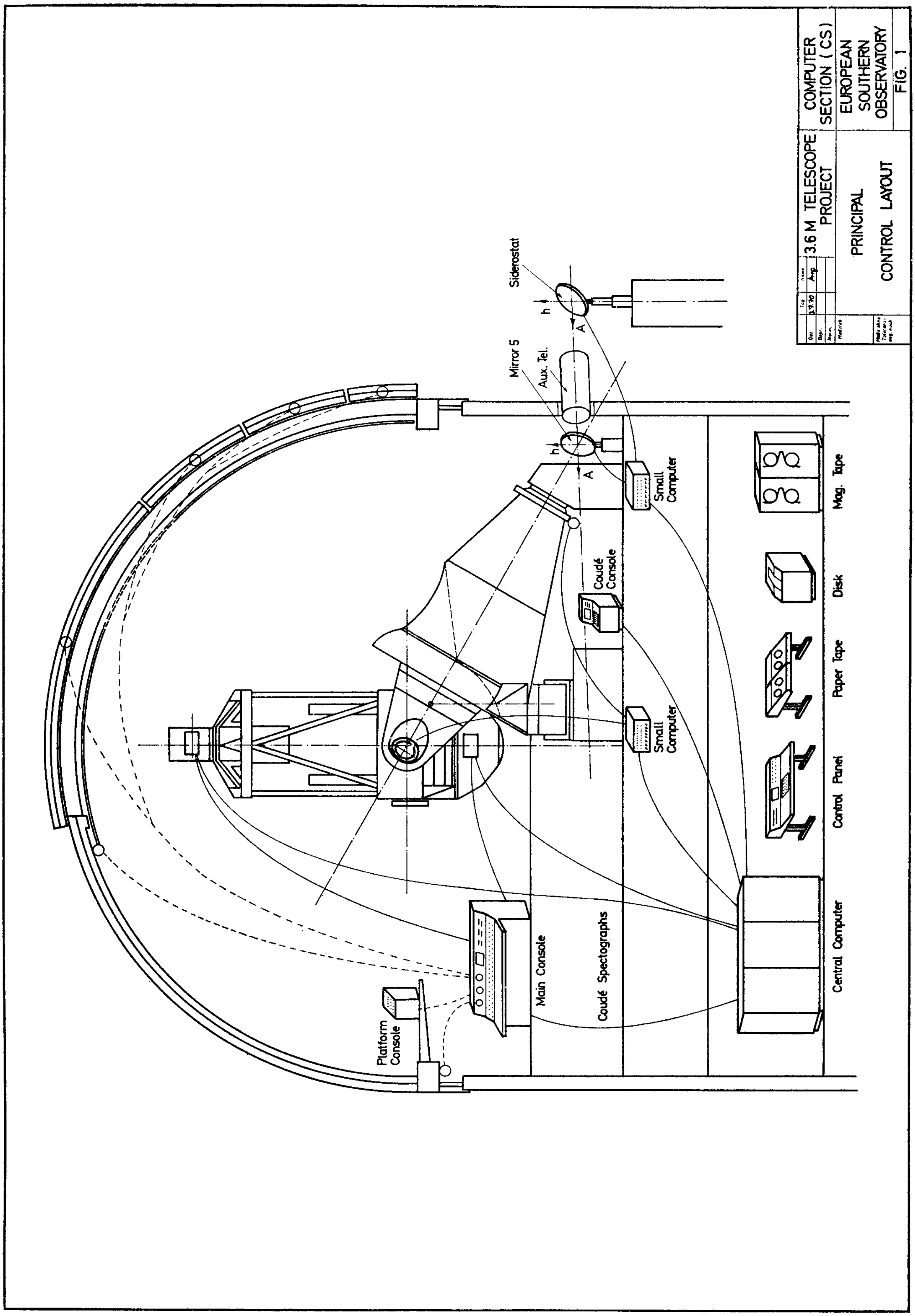
By applying all these corrections to the catalogue values, the preselected coordinates are obtained.

This method could also be used in a reversed mode as proposed at McDonald Observatory. By reducing the observed positions of non program filed stars with these corrections, one gets the coordinates of a standard equinox which can be stored in the file.

TELESCOPE DRIVE CONTROL (Figs. 2 and 3)

The actual position of the telescope is assumed to be given by digital encoders, preferably absolute ones. If incremental encoders should be used, external counters should be foreseen. Thus, the computer gets the positions in parallel form. Code conversions could be required, in the worst case both for the computer and for an external display for the observer.

The actual and preselected coordinates are compared in a comparator. With an encoder resolution of 1 arcsec, this comparator has to have 20-bits length to cover the telescope moving range. The



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difference value, or the output from the comparator, will be used to bring the telescope to the desired position. This is being done by a speed controller, a rate generator and an error counter.

The dynamical behaviour of the telescope puts an upper limit on the speed allowed and determines the proper acceleration characteristics when going from zero to full speed, or in reverse for deceleration.

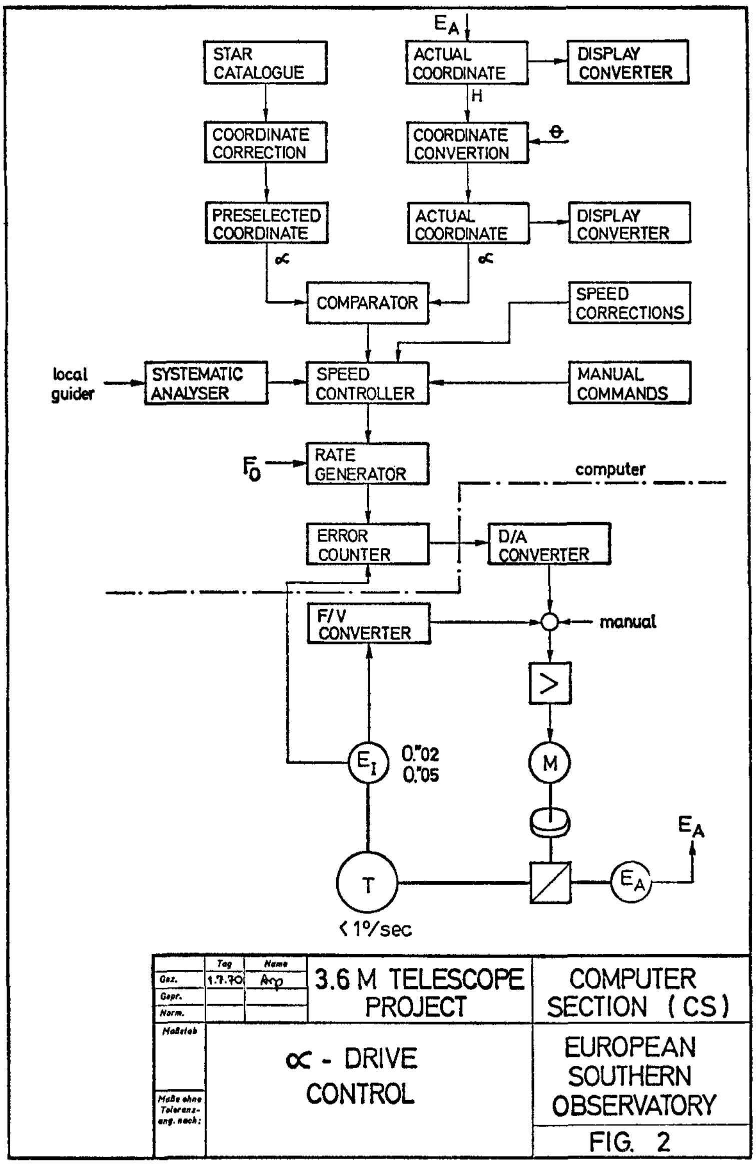

Fig. 2

The speed controller has to take account of these circumstances and to calculate the desired speed at suitable time intervals. Assuming a highest telescope speed of 1° per sec and acceleration/deceleration times of 5 sec, it turns out that the telescope should be slewed at full speed for comparator outputs of about 5° and higher. The acceleration/deceleration curves, according to which the speed controller shall control the drive motor, obviously has to be empirically determined. However, it would be sufficient to calculate, according to these curves, the desired speed every 10 or 100 msec. This time could be varied inversely to the frequency of the rate generator, as the calculations need not be made so often at full speed (the horizontal part of the speed curve), and as the rate generator and error counter will occupy much more time at the higher speeds.

DOME CONTROL (Fig. 4)

The figure shows the situation when the dome has to be moved to a new position. A somewhat modified scheme applies to the situation when the dome has to follow the telescope during observation.

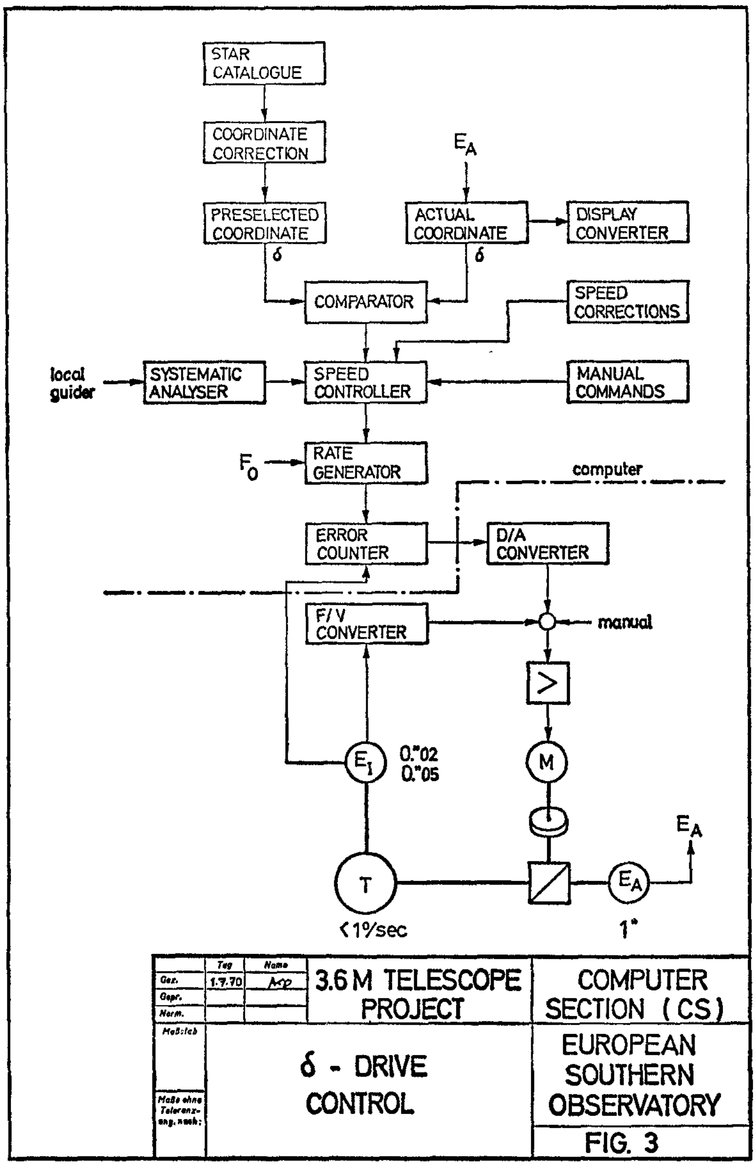

Fig. 3

We assume that the dome to be controlled has some kind of shutters, which will be opened to discrete positions, and a windscreen, which can be put to any desired position. The shutters could be either the common type of long shutters going to each side, or the type sliding along the opening.

The solution shown in the figure applies to the latter type, where the shutter is divided into several shorter hatches, anyone of which can be controlled separately. The position indicated only has to be from a few position switches. By comparing the preselected position of the telescope, after conversion to alt-azimuth coordinates, with the actual position of the shutters, control commands can be given to anyone of the hatches to move in one or the other direction. The solution should be such that any other hatches in the moving direction automatically move along.

Both the dome and the windscreen have to be provided with encoders. The dome requires a 10-bit and the windscreen an 8-bit encoder to give a linear resolution at the periphery of about 10 cm. Here also, converted telescope and dome positions are compared and the drive commands are executed. In this case, however, the devices can be controlled to any desired position with an accuracy of the

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resolution of the encoders. The positions are, furthermore, converted from the binary computer code into convenient units for the observer's displays.

COUDÉ MIRROR 5, *SIDEROSTAT AND DOME* (Fig. 5)

The optical layout of the ESO 3.6-metre telescope is such that the coudé beam is transmitted obliquely through the polar axis. Having passed along the polar axis, it is reflected by mirror 5 into

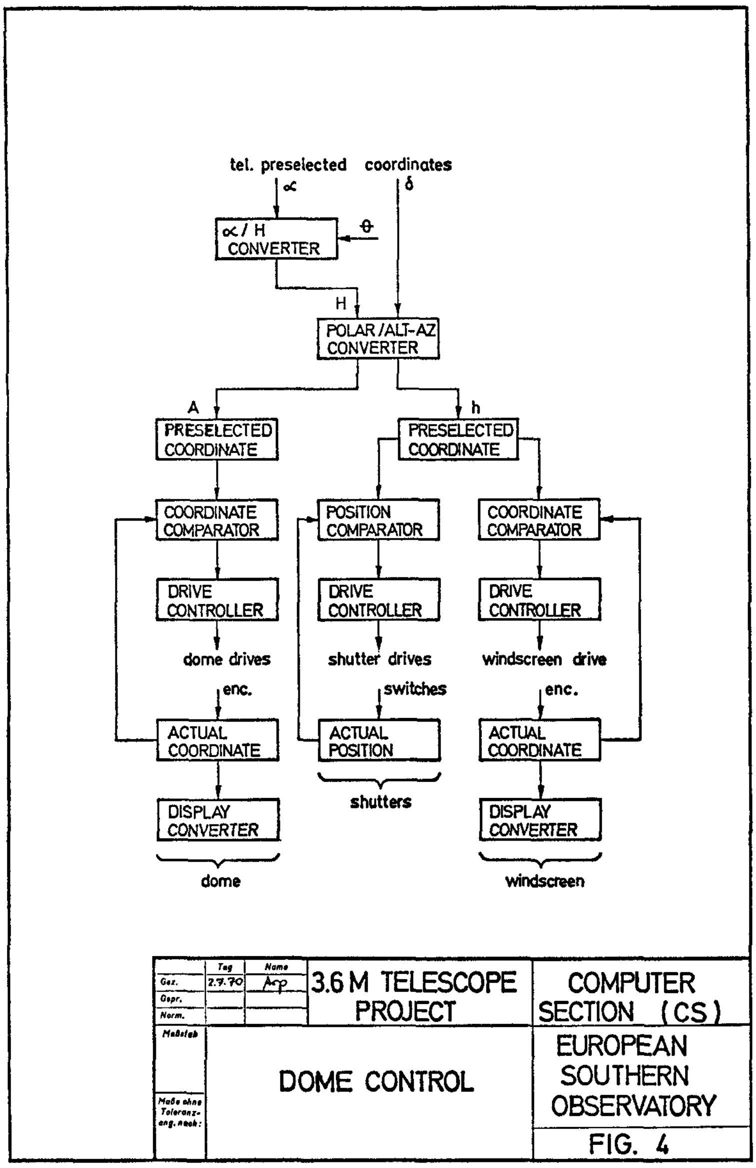

Fig. 4

the nearly horizontal coudé laboratory. Mirror 5 can be removed and the light path from an auxiliary telescope and siderostat mirror can be fed into one of the coudé spectrographs. This arrangement would permit use of the rather expensive coudé laboratory, at least for bright objects, even when the main telescope is being used for prime focus or Cassegrain focus work.

Pointing of mirror 5 is done in the following way. The preselected coordinates for the telescope, right ascension (α) and declination (δ), are converted first into hour angle (H) and declination and then into azimuth (A) and altitude (h), which are the preselected coordinates for the mirror. These coordinates and the actual coordinates from the mirror encoders are compared and the difference is fed to one speed controller for each drive.

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When the preselected position is reached, the mirror has to start its tracking motion. This has to take place in both axes and the speed has to be computed out from the tracking speed of the telescope, corrected for refraction, and from the actual coordinates of the mirror. A command controller takes care of these commands, manual commands and commands from the automatic guider. These commands are executed by the speed controllers. The detailed function of this unit depends upon the type of drive being used for the mirror.

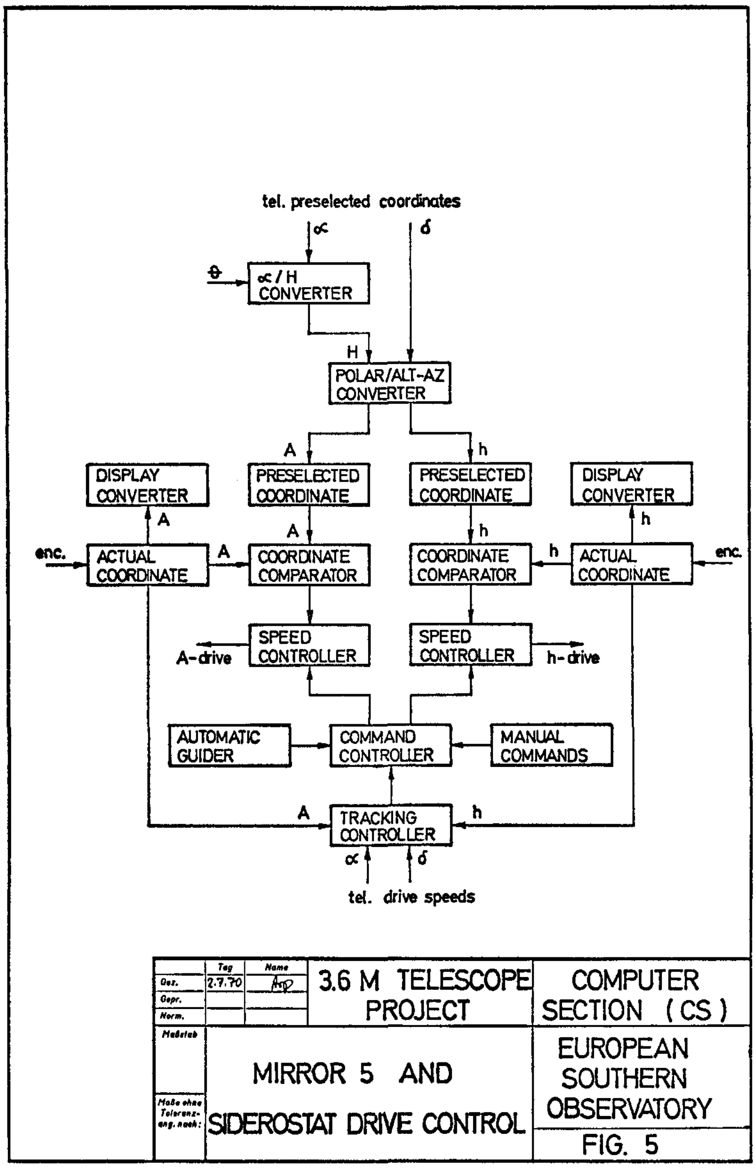

Fig. 5

The auxiliary telescope is fixed in position, but the siderostat mirror has to be driven in very much the same way as coudé mirror 5. The drive of the dome covering the siderostat mirror has to be controlled in a similar way as the main dome.

The actual coordinates are converted into suitable display units, which is necessary on account of the fact that the mirrors and the dome cannot be observed from the user's position.

AUTOMATIC GUIDING (Fig. 6)

Automatic guiders of different kinds (prism, dissection tube, or TV guiders) are normally used to guide with the telescope drives directly. In principle a better solution is to move only the focus unit instead of the whole telescope. In this way a faster response can be achieved.

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Such a local guider for the prime and Cassegrain foci could consist of an X-Y-driven plate holder unit. The two screws are provided with absolute encoders of a resolution of about 5 μm as referred to the photographic plate, corresponding to 0.1 and 0.3 arcsec in the sky. At suitable time intervals the X and Y encoders are sensed, and the results of repeated measurements are treated by a systematic analyser. If a systematic drift appears, in that the encoder values are systematically increasing or

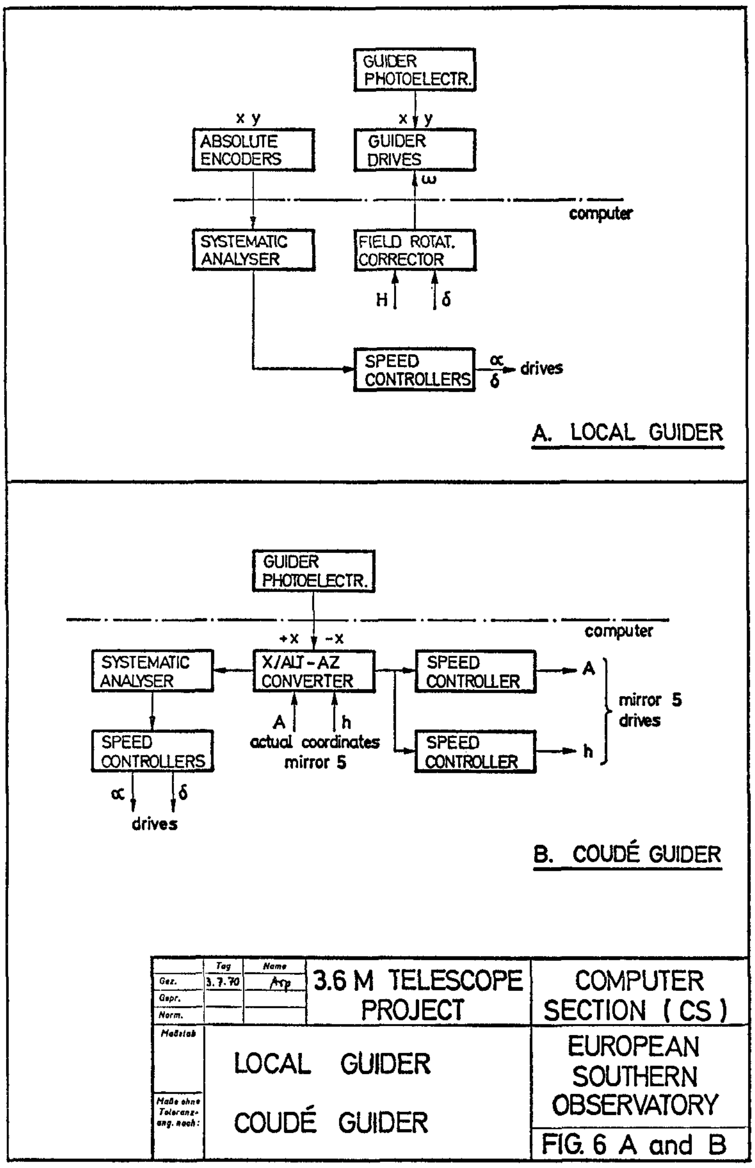

Fig. 6 A and B

decreasing, a corresponding speed correction is calculated and fed to the speed controller of the α and δ drives. By this means a systematic drift of the local guider is avoided.

In this way one can automatically take care of:

1. errors in drive gears,
2. speed changes which should have been required due to refraction effects in different observation directions,
3. moving objects such as moon and planets.

The other way would be to make a systematic, empirical analysis of the gear errors and to store them in the computer, to compute speed corrections due to refraction, and to feed the computer with information on moving objects.

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This local guider also offers another interesting possibility. The photographic errors caused by differential refraction over the photographic plate can to some extent be compensated by applying a field rotation of suitable amount.

Automatic guiding at the coudé spectrographs can be performed by mirror 5. Control signals are taken from the slit flanges for guiding in the X-direction (the direction of the slit width). These signals

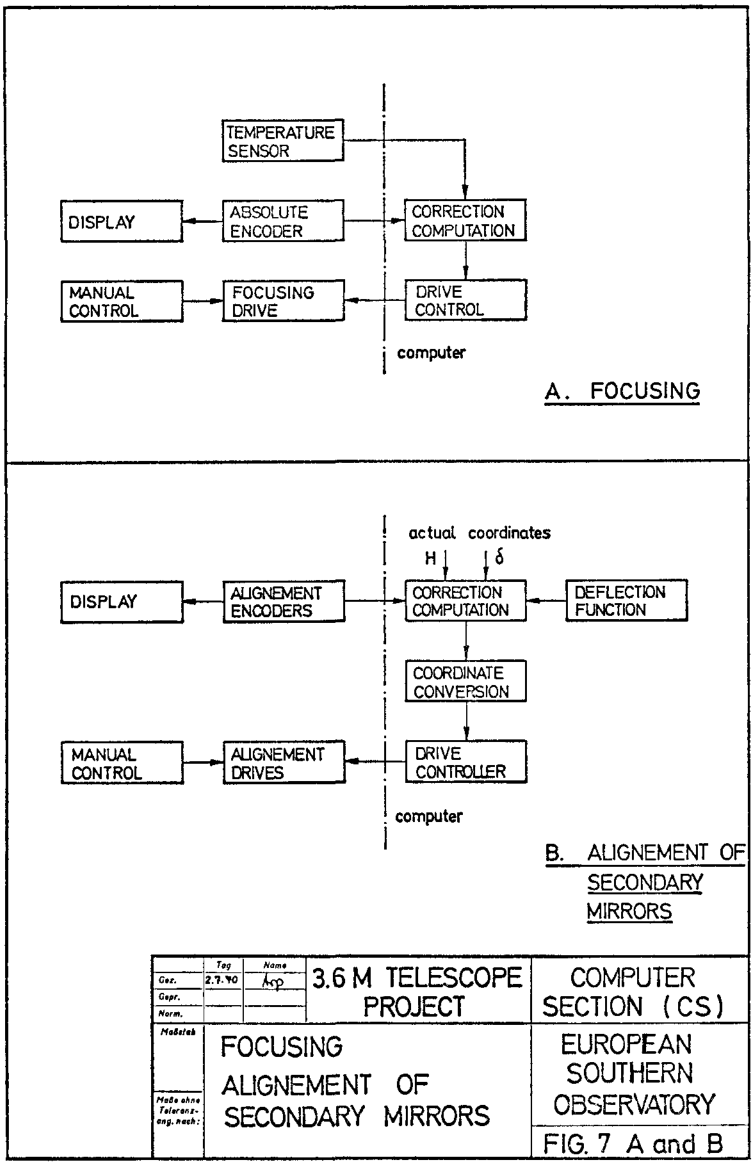

Fig. 7 A and B

have to be converted into corresponding alt-azimuth values, related to the actual direction of mirror 5. These signals then control the mirror 5 drives via two speed controllers. They are also fed to a systematic analyser, which gives corrections to the speed controllers of the α and δ drives for the telescope.

FOCUSING (Fig. 7A)

Automatic *focusing* has earlier mainly been used on Schmidt telescopes, where invar bars of suitable lengths have been introduced to compensate for the differential temperature expansions of mirror and tube materials. Another possibility is, of course, to measure the temperature and to make corrections according to the temperature fluctuations. Suitably placed temperature sensors feed

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digitized temperature values into the computer. Information is also fed from an absolute encoder on the drive of the focusing mechanism. These two values are put into an equation for computation of the correct focus position. The corresponding focusing is carried out by a drive control unit. As the temperature varies only by small amounts during one night—at La Silla not exceeding 5°C—these corrections can be made at intervals of the order of one or a few minutes.

ALIGNMENT OF SECONDARY MIRRORS (Fig. 7B)

As described earlier, the deflections of the tube give rise to corrections both as to the coordinates by positioning and to the tracking speed. But they also give a misaligning effect on the optical parts. This means that the secondary mirror gets a lateral shift in relation to the primary mirror. A shift of the order of 0.5 mm can be tolerated, but the shift can be larger. The optical effect of this shift is a field-independent coma, which can be compensated for—within a range of 2–3 mm—by tilting the secondary mirror. This is a much simpler and safer method than shifting the whole mirror unit laterally. Furthermore, three screws will at any case be available for the optical alignment. By motorizing these screws and providing each of them with an encoder, it is possible to automate this procedure.

The deflection of the telescope first has to be determined empirically and a function or a curve has to be stored in the computer. The corrections can then be computed at any occasion, from this function and the actual H and δ coordinates. By concerting these values into a coordinate system defined by the three screws, the actual corrections can be applied to the alignment drives via suitable drive controllers.

OTHER COMPUTER FUNCTIONS

In order to optimize the observation times, the computer could be used to assist in determining required exposure times. The parameters which should be considered in the computation would be filter combination, photographic plate, type of stars of main interest, magnitude range, etc.

Another field, where new investigations could be made with a computer available, is the behaviour of the instrument itself. We could think of such things as studies of the behaviour of the main mirror in its cell.

By using the computer, a reasonably extensive log-book could be arranged without putting any further burden on the observers This log-book should contain all interesting information about the telescope itself, the environment (meteorology), the auxiliary instruments, the observation program, etc.

Our principal idea in programming a control system, like the one outlined here, is to have a couple of program sets, which are to be executed repeatedly with different time intervals These time intervals can vary from, say, 10 msec up to the minute range.

DISCUSSION

E. W. DENNISON: How are you going to connect the equipment on the telescope and dome with the central computer?

B. MALM: We are planning for cables through the polar and declination axes, but we shall have to use telemetry to and from the dome.

A. A. HOAG: What is the nature of the photoelectric detector for guiding and for image quality assessment?

B. MALM: We have a proposal from a German company for a standard guider, built on the normal prism-photomultiplier principle. But we are also considering television and lock-on tracking.