A Digital Computer as Process Controller of a 2.2 m Ritchey-Chrétien Telescope

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In 1969 a new astronomical institution was founded in the Federal Republic of Germany. This "Max-Planck-Institut für Astronomie" will consist of a central institute at Heidelberg and two observatories, one in the South-East of Spain and one in the Southern hemisphere (possibly in South-West Africa). Each observatory will be equipped with a 2.2-metre Ritchey-Chrétien telescope; these instruments are now under construction at Carl Zeiss, Oberkochen, Western Germany. In addition, a 3.5-metre telescope will be built. A smaller Ritchey-Chrétien telescope of 1.2 m will go into operation next year in Spain. The mirror disks of the 3.5-metre and 2.2-metre telescopes have been ordered from Schott & Gen. at Mainz; they are made of glass ceramic "Zerodur", a zero-expansion material similar to CerVit. In the operation of the 2.2-metre telescopes and their peripherals, small, general purpose digital computers will be employed.

1. *GENERAL SPECIFICATIONS OF THE TELESCOPE-COMPUTER SYSTEM*

Our design of the computer control of the telescope provides the possibility of giving instructions to the telescope, immediately by hand. In case of a computer breakdown a simpler mode of telescope operation is possible, without severe restrictions. Table 1 summarizes the operations of the telescope without and with the computer.

TABLE 1

TELESCOPE OPERATIONS WITHOUT AND WITH THE COMPUTER

Operations of the 2.2m—Ritchey-Chrétien Telescope

Without the computer	With the computer integrated
Display: U.T.	Display: U.T., S.T., J.D.
Reading the telescope position from classical circles	Display: α, δ, corrected for refraction, flexure, circle errors (± 10 arcsec); Display: H.A., altitude, azimuth; Display: α, δ Preset: α, δ, Eq., α, δ, $\triangle\alpha$, $\Delta\delta$
Setting and slewing the telescope; moving the dome and windscreen; pushbutton control	Positioning the telescope (± 10 arcsec), dome and windscreen under program control; differential positioning (± 1 arcsec)
Tracking at sidereal rate controlled by fixed frequency derived from the digital clock	
Guiding by pushbuttons (rate 2 arcsec/sec or single step 0.1 arcsec) or star sensor	
	Control of corrections α, δ: taken from the present unit and/or calculated from position coordinates (due to changing refraction, flexure) and/or derived from integrated empirical guiding corrections or plateholder operations
	Control of the optimal plateholder rotation (due to differential refraction etc.)
	Control of automatic refocussing (due to thermal and mechanical change of the tube length)

2. *TELESCOPE DRIVE HARDWARE*

The driving systems for both axes consist of single worm wheels, used for both tracking and slewing. The declination and right ascension drives are functionally identical except for the sidereal

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tracking. Oil-pad bearings are provided for the declination axis as well as for the hour axis, to get a higher guiding accuracy.

Figure 1 shows the operational scheme of the right ascension drive. We use only one motor for slewing, setting, tracking and guiding purposes. This Servalco motor is essentially a d.c. motor (reversed unipolar machine); its integrated electronics allows to operate it as a d.c. motor (analog input) as well as a "stepping motor" (frequency input, binary input). The development of these electronics is done

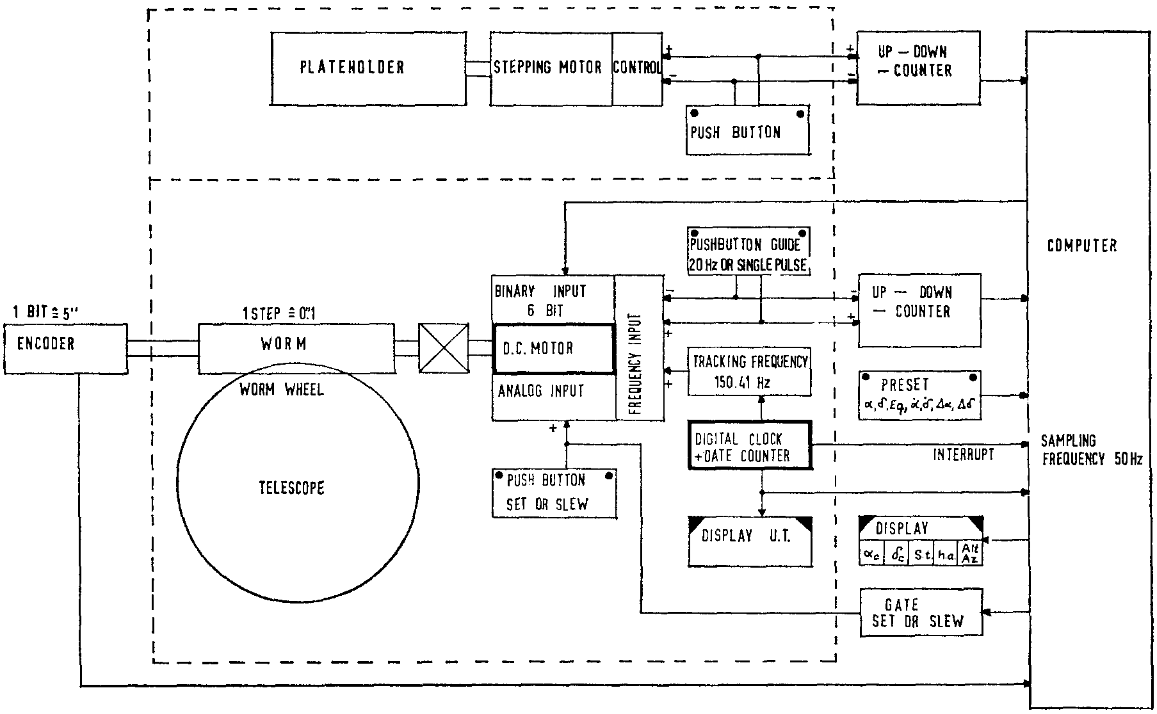

Fig. 1
Proposed operational scheme of the right ascension drive.

at Carl Zeiss, and no details can be given at this moment. The general functions may be summarized as follows:

(*a*) *analog input*: provides for slewing (100°/min) and setting (2°/min); controlling the acceleration phases;

(*b*) *frequency input*: each pulse is followed by one step, corresponding to 0.1 arcsec in telescope position; up to three independent frequencies (up to 1200 Hz, for both directions) can be fed into this input device without loss of any pulse;

(*c*) *binary input*: a binary coded integer (6-bit) given to this input device will cause an equal number of steps to be performed smoothly during the following well-defined time interval of 0.02 sec (*e.g.* the integer 10 causes 10 steps at a rate of 10 per 0.02 sec, corresponding to 50 arcsec per sec angular rate). The direction of the motion is determined by the first bit.

3. *OPERATIONS OF THE TELESCOPE INDEPENDENT OF THE COMPUTER*

Operations independent of the computer are surrounded by dashed lines in Figure 1. Slewing and setting can be done by pushbuttons connected to the analog input of the motor. Tracking at sidereal rate is performed by operating the motor as a stepping motor, feeding the corresponding frequency, controlled by the digital clock, into the frequency input. For guiding purposes the same input device allows the superposition of a lower frequency (rate: 2 arcsec s^{-1}) or single pulses (step: 0.1 arcsec) in both directions, controlled by pushbuttons. Instrumental coordinates can be read from classical circles at the instrument. The display of Universal Time is independent of the computer.

4. *SPECIFICATION OF THE COMPUTER CONFIGURATION*

The computer configuration to be integrated in the telescope control is outlined in Table 2.

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TABLE 2

COMPUTER CONFIGURATION

Central unit	Memory cycle:	1.6 μs
	Memory capacity:	8192 words
	Wordlength:	16 bits
	High speed arithmetic	
Interface	Priority interrupt lines:	8
	Digital input lines:	160
	Digital output lines:	64
Periphery	Teletype	
	Card reader and tape reader	
	Preset and program switches	
	Display unit	
	Gates	
	Encoders	
	Up-down counters	

5. *DISPLAY CONTROL*

The computer is monitored by the digital clock. The computer gets an interrupt signal from the clock at a rate of 50 Hz. Once the absolute time, binary coded, has been given to the computer, it generates several time measures at each moment (*e.g.* Sidereal Time or Julian Date). Other cycling subroutine programs can be triggered at rates less than 50 Hz. For example, at a rate of 4.5 Hz the computer reads data from the encoders attached to the worms. This binary information is converted to Hour Angle (or Right Ascension) and Declination, corrected for refraction, flexure, decollimation and circle errors. We hope that the error of the corrected position will be of the order of 10 arcsec. Transformations of H.A. and Dec. to Altitude and Azimuth can be done easily. The corrected or transformed coordinates and the different time scales can be given cyclically to the display unit at the same rate.

6. *POSITIONING UNDER PROGRAM CONTROL*

After the operator has given the coordinates—α, δ and the equinox—to the preset unit (card reader or switches), the computer will drive the telescope, dome and windscreen to the desired position, if this is an allowed one. The coordinates will be corrected for precession and the instrumental position for refraction, flexure, pole deviation, circle errors etc., using parameters derived empirically and stored in the computer. The slewing and setting gates, connected to the analog input of the motor, are controlled by cyclic comparison of the actual coordinates from the encoders with the given ones. At the end of the setting phase, the tracking frequency drives the telescope at sidereal rate. The residual deviations from the desired position $\Delta\alpha$, $\Delta\delta$ (several minutes of arc) are derived from encoder data. The corresponding number of steps of 0.1 arcsec will be given ratewise to the binary input of the motor. During each sampling cycle of 0.02 sec the maximum number of 24 steps will be smoothly performed (angular rate: 2 arcmin s^{-1}) until the total number has been executed.

The same procedure can be used in the tracking mode (*cf.* the next section), if the computer is so instructed, via the preset unit, to perform a well-defined displacement $\Delta\alpha$, $\Delta\delta$ (up to 1°) in the telescope position with a high degree of accuracy.

7. *CONTROL OF ADDITIONAL ANGULAR RATES*

The sidereal tracking rate in H.A. and zero tracking rate in Dec. have to be modified for several reasons. This can be done by superposition of the corresponding frequency to the tracking frequency. The binary input device of the motor is used to solve this problem in a very simple manner. To any angular rate $\dot{\alpha}$ or $\dot{\delta}$ corresponds a certain number of steps to be performed during each sampling cycle of 0.02 sec. By cyclically giving the corresponding integer to the binary input, the computer drives the telescope at any required rate in addition to the clock-controlled sidereal rate. (*e.g.* $\dot{\alpha}=1$ arcsec s^{-1} corresponds to the integer 1, transmitted each fifth cycle; if $\dot{\alpha}=7.5$ arcsec s^{-1}, the computer gives alternatively the integer 1 and 2 each cycle.)

In this way, modifications of the track rate due to changing refraction, flexure etc. can be performed under program control, using constants derived empirically. Or, via the preset unit, angular

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rates can be fed in, to track objects with significant apparent motions known a *priori* (moon, comets etc.,) and for drifting and scanning purposes.

During tracking, pointing corrections can be done by hand, feeding a lower frequency or single pulses into the frequency input device of the motor. All these correction pulses are counted by up-down-counters connected to the computer. By cyclic inspection (rate: 1.2 min) the computer derives from the counters the net number of steps in the prevailing directions. From this, for the next cycle, the corrected number is calculated that will be transmitted at the sampling rate to the binary input of the motor. In other words, the *uniform* rate for the new cycle corresponds to the *average* rate—including hand corrections—of the last one.

If the pointing corrections are performed at the plate-holder, a similar procedure has been provided. The plateholder is moved by stepping motors in X-Y coordinates and the steps are counted by up-down-counters. From the effective number of steps performed during the last cycle, the computer calculates the corresponding corrections to be given to the telescope drive during the next cycle.

8. *FURTHER FACILITIES PROVIDED*

Of the facilities further provided we mention only the following four:

- control of the optimal plateholder rotation due to differential refraction etc.;
- control of refocussing due to thermal and mechanical change of the tube length;
- control of scanning operations etc.;
- writing a log-book of telescope operations.

We wish to thank Mr. J. Neumann and his colleagues at Carl Zeiss for their contributions to the design of the telescope-computer system that we have described.

DISCUSSION

C. L. STEPHENS: What computer system will you be using?

J. SOLF: A Honeywell H316.

N. N. MIHEL'SON: Will there be a photoguidance system in the 2.2-metre telescope?

J. SOLF: Yes. If guiding is performed by a star-sensor, the computer has a similar function to that described in the case of hand-guiding. From the net number of correction steps controlled by the star-sensor during each cycle, the computer derives and controls the corrected uniform rate for the next cycle.

C. N. W. REECE: What protection do you have for the worm and wheel against failure of the drive system, particularly during slew?

J. SOLF: That is not given to the computer control because we want to operate the telescope without computer, and so it must be integrated in the control of the motor itself.

E. W. DENNISON: Normally I believe the procedure is to put a large effective inertia on all of the high speed shafts. Since the inertia multiplies as the square of the gear ratio, you in fact don't need a very large flywheel to dominate over the telescope inertia.

C. N. W. REECE: Yes, that is one way. I realize this does protect the servo insofar as you are slowing down the response rate of the servo control by having to do that.

E. W. DENNISON: That's right, although as Dr. Dunn pointed out, nature has handed up telescopes which in general oscillate at fairly low frequencies, and therefore you don't need to take a very big penalty there, if one doesn't try and servo at high frequencies.

C. N. W. REECE: This is just why we're interested in friction drive, using the inertia of the telescope itself as the main controlling feature in the system. One can build in safety factors quite easily there.

G. S. WALKER: Since the digitization of the telescope axis is at the worm shaft, how are the errors of the worm and wheel corrected?

J. SOLF: This is the manufacturer's responsibility.