TELESCOPE CONTROL BY COMPUTER

PROGRAMM ABLAUF TELESKOP STEUERUNG

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Keywords : Telescopes, Computer control, Micro Computer, Industrial Process, Control, Astronomy, Data Acquisition, Automation.

ZUSAMMENFASSUNG

Das Programm Teleskop Steuerung wird erlaeutert anhand von dargestellten Betriebsfällen, die im einzelnen untersucht werden. Ausgehend von der Ruheposition des Teleskops und der Positionsvorgabe per Terminal durch den Operator werden die einzelnen Funktionen beim Ablauf der Steuerung beschrieben und ihr Zusammenwirken aufgezeigt. Die Steuerung ist mit einem intelligenten Front-end Prozessor (Micro-Computer 6800) mit Ansteuerung der Motor und Feedback-loop Routinen, sowie Data Acquisition der Anlage realisiert. Die Programmierung der Steuerung ist im Host Rechner in FORTRAN (Honeywell-Bull Mini 6) realisiert und kommuniziert mit dem Micro per serieller Schnittstelle. Ein Funktionenbeschrieb der Hardware befindet sich unter dem file doc_13.09.di auf dem Mini 6 der Sternwarte Alterswil.

ABSTRACT

The telescope control program is explained under actual operating conditions which are investigated in detail. Departing from the rest position of the telescope and position preset per terminal by the operator, the individual functions of telescope control are described and their interaction explained. Control is implemented via an intelligent front-end processor (micro-computer based on a 6800 CPU) with control of motors and feedback loop routines, as well as data acquisition in the observatory. Programming of telescope control is implemented in the host computer (Honeywell-Bull Mini 6) in FORTRAN and communicates with the micro per serial interface (RS 232C). Hardware description is found under the file doc_13.09.ui on the Mini 6 at Alterswil Observatory.

INTRODUCTION

The philosophy of telescope control is varied. With the increasing interest and importance of micro computers as complete units in industrial process control and data acquisition, a system is implemented via an intelligent front end processor based on a modular unit employing a 6800 CPU with peripheral subsystems to effect the necessary functions and interactions required for telescope control. The micro employed is a standard industrial product in order not only to offload the host computer and to free it for other tasks such as online data acquisition at the telescope for astronomical purposes, but also to assure the user to have access to a widely utilized soft- and hardware

implementation with standard industrial products available for service and maintenance and further expansion without having to change the entire telescope control structure. At the micro, simply adding more cards for specific tasks to the card cage and loading and formatting the software subroutines can expand a system efficiently and in a short time.
The serial interface on the RS 232C basis assures system transportability to all host computers with little software adaption work. Communication sub-routines only have to be written for the host in question. As the micro carries sufficient intelligence for all telescope control functions, and the control software in the host is written in a transportable, standard set of FORTRAN, implementation on another host computer can be realised quickly.

This telescope control system implementation is based on a Honeywell-Bull Mini 6 computer, data transfer from the host resident software to the micro is at 19200 bps.

SYSTEM START

An operator dialog precedes all interactions host/micro telescope. A description of this dialog is found in the masks for operator interaction after signing on (see idem). After the operator types his code into the host computer, questions are asked as to the nature of the observation and operation, which instruments are to be used, what is the intended observing period, which object coordinates the telescope is to go to. The dialog rests on the fact that the rest position (*restpo*) of the instrument is known. In case this position is unknown (due to manual operation of the telescope without computer interaction), the operator is first requested to bring the telescope manually onto a known star with position close to the site zenith for avoiding errors due to refraction, etc. Once this position is input, the telescope synchronizes itself as to sidereal time, universal time, hour angle, etc.

TIME STANDARDS

The internal standard of time keeping and reference point is sidereal time for the site longitude in comparison with universal time (= Greenwich Time). Sidereal time (*sidert*) is the hour angle of the vernal equinox and measured in a 24 h format. Sidereal time is 3 min 56.555 sec shorter than universal time. Both times are equal on March 21 at 00 h 00 min 00 sec and counted up. Sidereal time is provided in the computer via a sidereal time clock with a quartz base of 10^e6 accuracy. Universal time is provided via a time signal DCF 77 in Europe or via a precise quartz clock in the case of the Kuwait telescope system (accuracy 10^e9). Sidereal time, hour angle, and object coordinates are linked in the following manner: sidereal time is the hour angle of the vernal equinox. Alpha (the object coordinate) is the angle counted in hours from the Vernal Equinox to the object; counting direction is positive in a West to East direction. A little diagram will explain the relative functions:

```
                               ^
                               :
                               :  LOCAL SIDEREAL TIME
                ALPHA OR       : <-------------------<0> VERNAL EQUINOX
 OBJECT *<------------------------------------------- :   00H 00MIN 00SEC
        :   RIGHT ASCENSION    :                               S.T.
        :                      :
        :--------------------->:          <---POSITIVE COUNTING DIRECTION
             HOUR ANGLE EAST   :              IN HOURS
                               :
                               :
EAST ==========================+============================== WEST
                           MERIDIAN
                            SOUTH
```

TELESCOPE COORDINATE INPUT

Coordinate information is provided via incremental encoders on both axes with a resolution of 0.1" and 0.2" (arc seconds) for alpha and delta, respectively. The encoders are mounted via rollers directly onto the axis in question, their signal is in a quad b mode allowing a readout of four times the amount of increments on the disc. From this setup follows a high accuracy of the machined axes and encoder shafts to reduce errors in readout to a minimum.

TIME FLOW DIAGRAM

The following time flow diagram gives an overview of the priorities and interactions of the individual functions of the telescope drive control system.

(1) Rest Position of telescope is known:

```
+-----------------+
I OPERATOR DIALOG I
+-----------------+
   I
   I          +----------------+
   I--------->I UNIVERSAL TIME I
   I          +----------------+
   I
   I          +---------------+       +------------+
   I--------->I SIDEREAL TIME I------>I HOUR ANGLE I
   I          +---------------+       +------------+
   I                                    I
   I                                    I                       +-------+
   I                                    I                       I LIMIT I
   I                                    I                       +-------+
   I                                    I                           I
   I    +------------+    +--------------+    +------------+    +-------+
   I--->I REST ALPHA I--->I PRESET ALPHA I--->I OBJECT POS I--->I GUIDE I
   I    +------------+    +--------------+    +------------+    I-------+
   I                                                                I
   I                                                           +---------+
   I                                                           I CORRECT I
   I                                                           +---------+
   I
   I
   I     +------------+    +--------------+    +--------------+ +---------+
   I---->I REST DELTA I--->I PRESET DELTA I--->I DELTA OBJECT I-I CORRECT I
   I     +------------+    +--------------+    +--------------+ +---------+
   I
   I
   I     +-----------+     +-------------+     +---------------+
   I---->I REST DOME I --->I PRESET DOME I---->I POSITION DOME I
   I     +-----------+     +-------------+     +---------------+
   I
   I     +--------------+
   I---->I OPEN SHUTTER I
   I     +--------------+
   I
   I     +----------------+    +--------------------+
   I---->I FOCUS POSITION I--->I NEW FOCUS POSITION I
   I     +----------------+    +--------------------+
   I
   I                     +-------------+
   I     +---------+     I TEMPERATURE I
   +---->I SENSORS I-----I HUMIDITY    I
         +---------+     I PRESSURE    I
                         +-------------+
```

Explaining the above time flow diagram in more detail takes on the following format (departing from the operator dialog) for **the ALPHA AXIS**:

```
\ /
 I
 I   +---------------------------------+
 I-->1 READ UT   COUNT UT   DISPLAY UT I
 I   +---------------------------------+
 I
 I   +---------------------------------+
 I-->I READ ST   COUNT ST   DISPLAY ST I
 I   +---------------------------------+
 I                  I
 I                  I                                +-----------------+
 I       +--------------------------------------+    I           ALPHA I
 I       I CALCULATE HA   COUNT HA   DISPLAY HA I--->I CALC LIMIT      I
 I       +--------------------------------------+    I           DELTA I
 I                              I                    +-----------------+
 I                              I
 I   +---------------------------------------------------------------- +
 I-->I READ RESTPOS ALPHA   DECREMENT RESTPOS BY ST   DISPLAY RESTPOS  I
 I   +-----------------------------------------------------------------+
 I
 I   +-------------------------------------------+
 +-->I READ PRESET ALPHA   DISPLAY PRESET ALPHA  I----------+
     +-------------------------------------------+          I
                                                            I
 +----------------------------------------------------------+
 I
 I   +------------------+  +-----------------+  +----------------------+
 +-->I SLEW ALPHA MOTOR I--I SET ALPHA MOTOR I--I PRESET ALPHA REACHED I
     +------------------+  +-----------------+  +----------------------+
                                                           I
                               +                           I
 +---------------------------------------------------------+
 I   +-------------+   +----------------------+   +------------------+
 +-->I GUIDE ALPHA I-->I CORRECT ALPHA (HAND) I-->I STORE CORRECTION I
     +-------------+   +----------------------+   +------------------+
                                                           I
                                                           I
 +---------------------------------------------------------+
 I
 I
 I   +----------------------------+
 I   I                COMPUTER    I   +------------------------------+
 +-->I GUIDE ALPHA BY AUTO-GUIDER I-->I WARNING LIMIT SWITCH +15 DEG I
     I                HAND PANEL  I   +------------------------------+
     +----------------------------+                 I
                                      +------------------------------+
                                      I  LIMIT SITCH +10 DEG REACHED I
                                      I     STOP ALL MOTORS          I
                                      +------------------------------+
                                                    I
```

```
                                       +-------------------------------+
                                       I  OVERRIDE ONLY BY REVERSING  I
                                       +-------------------------------I
```

DELTA AXIS FLOW DIAGRAM

```
\ /
 I
 I
 I        +-------------------------------------+    +------------------+
 +------->1 READ RESTPOS DELTA    DISPLAY DELTA I--->I CALC LIMIT DELTA I
     I    +-------------------------------------+    +------------------+
     I
     I    +--------------------------------------+
     +--->I READ PRESET DELTA     DISPLAY PRESET I----+
          +--------------------------------------+    I
                                                      I
     +------------------------------------------------+
     I
     I   +-------------------+      +------------------+
     +-->I SLEW DELTA MOTOR I------>I SET DELTA MOTOR I----+
         +-------------------+      +------------------+    I
                                                            I
     +------------------------------------------------------+
     I
     I    +----------------------+   +----------------------+
     +--->I PRESET DELTA REACHED I-->I CORRECT DELTA (HAND) I---+
          +----------------------+   +----------------------+   I
                                                                I
     +----------------------------------------------------------+
     I                                 +-------------------------+
     I    +------------------------+   I                    HAND I
     +--->I STORE DELTA CORRECTION I-->I CORRECT DELTA COMPUTER I
          +------------------------+   I             AUTO-GUIDER I
                                       +-------------------------+
                                                   I
                                                   I
                                     +------------------------------+
                                     I WARNING LIMIT SWITCH +15 DEG I
                                     +------------------------------+
                                                   I
                                                   I
                                 +-------------------------------------+
                                 I LIMIT SWITCH DELTA REACHED +10 DEG I
                                 I         STOP ALL MOTORS            I
                                 + ------------------------------------+
                                                   I
                                                   I
                                  +------------------------------------+
                                  I OVERRIDE ONLY BY REVERSING MOTORS I
                                  +------------------------------------+
```

(2) REST POSITION OF TELESCOPE UNKNOWN

When the rest position of the telescope is unknown due to manual driving of the instrument without computer interaction, the operator dialog requests that the operator move the telescope via the control console and hand panel onto a known reference star, preferably located near the site zenith in order to cancel out all errors in position due to refraction. The mask in the operator dialog requires the reference star coordinate input, the telescope is moved by hand operation to the reference star and guided on the reference star. The set button on the hand panel is depressed indicating to the computer that the reference star is guided on properly and its coordinates correct.

The computer synchronizes itself on these given coordinates, deducing the new rest position and allowing coordinate input for observation. Procedure (1) is started with rest position known. Reference star coordinates are input for 1950.0 Epoch, star must be contained in the SAO Catalogue and should be reasonably bright in order to avoid confusion with another star in the vicinity. The computer transfers these coordinates to the year and time in question for synchronisation. The actual position for the object is calculated without moving the telescope back to rest position. This requires the alpha motor to continue guiding while the preset coordinates are input into the mask by the operator. The telescope then moves directly onto the new object coordinates.

FROM GUIDING POSITION TO NEW PRESET POSITION

When the operator wants to go onto a new object, the alpha and delta motors are kept in running mode (guiding and correction). The new coordinates are input from the console (mask), the computer calculates the new directions for the motors to turn the telescope to. Some conditions must be observed:

1. if alpha > 12 h and delta < (latitude - 10 degrees)
    then delta moves across the pole for new alpha in order to keep alpha movement < 12 h.
    This condition also holds true for positioning the telescope under first object acquisition.

1.1. this condition can only be applied if the instrumentation mounted to the rear of the primary cell clears the fork or other mount parameters (mount base).

CALCULATION OF ALPHA MOVEMENT

The alpha motor is given certain speed parameters which can be altered by the operator for his convenience. Some operators want to correct a guiding error quickly, others prefer slower correction speeds. These correction speeds are freely operator selectable within certain bounds.

The alpha slew speed (*slewal*) is given by the maximum speed the motor will turn, i.e. 3000 rpm equal to 90 degrees per minute of time. The ramp to achieve this slew speed is set to 3 seconds up and down.

The alpha set speed (*setalp*) is assumed to be ten times the guide speed or 10 seconds of time in one second of time or 150" arcseconds per second. It can he varied by variable resistor to twice this value or reduced to one quarter of this default value. The set ramp is one second up or down.

The guide speed (*guidea*) is 1 second of time per second of time or 15 arcseconds per second of time. It can be varied +/- 50 %.

In the above diagrams, the telescope was always at rest position while calculations of preset motion of the telescope were carried out in the computer. This requires in-/decrementing of the hour angle display and the telescope rest position.

An alternate solution can be thought of as follows:

> When signing on, read rest position and start alpha motor in guide mode. This keeps the distance Vernal Equinox - telescope constant and facilitates the calculation of the preset alpha position. The guide speed is thus constantly superimposed on all operations. The hour angle is constant, pulses (increments) from rest position plus guiding are calculated and executed to arrive at preset alpha. In the previous case (telescope remaining in rest position) allowance for the time it takes the telescope to reach the preset alpha coordinates and adding the time pulses to this interval must be provided for.

ALPHA TIMING DIAGRAM

In order to illustrate the driving sequence, a short example of the speed versus time diagram is presented for the alpha motor:

```
SPEED
ALPHA                            SPEED / TIME DIAGRAM ALPHA MOTOR
MOTOR
  I
  I
  I
  + 3000 RPM       ---------
  I              //+       +\\                  PRESET ALPHA
  I            ////+       +\\\\                COORDINATE
  I          //////+       +\\\\\\              REACHED
  I        ////////+       +\\\\\\\\                I
  I      //////////+       +\\\\\\\\\\---------     I
  I    ////////////+       +          *********\\   I
  I   /////////////+       +          *********\\\\ I
  I  //////////////+       +          *********\\\\\============>
  0---------------------------------------------------------------------->
          RAMP        SLEW      RAMP     SET    RAMP    GUIDE
                                                                     TIME
```

DELTA AXIS MOVEMENT

The driving diagram for the delta motor is similar as to ramp and slew and set speeds. Since the motor only positions to the preset delta coordinate and then stops, the right hand portion of the above diagram is changed and only corrections for refraction and mechanical errors cause a short correction movement for the delta motor. Correction speeds are similar also to the alpha motor speeds with variable correction rates settable by the operator. For these speeds refer to "calculation of alpha movement".

COORDINATES AND CORRECTIONS

As stated previously, coordinates are input in 1950.0 Epoch and calculated for the current year the operator is observing. The preset values are shown in the mask when the computer drives the telescope onto the object. In the beginning, the preset coordinates given by the computer cannot be the exact location of the object due to several reasons: refraction parameters for the site, mechanical flexure parameters of the mount and telescope system driving inaccuracies in the gears and motors, etc. Only repeated synchronisation will approximate true object positions when the above parameters become known through experience and use. Starting with objects near the site zenith gives information about repeatability of position without refraction parameters.

A practical observing run will commence in the following manner:

1. The operator selects the reference star as described earlier and drives the telescope via control panel and hand console onto the star. The star is guided on and the set button to synchronize the computer is engaged.

2. As a next step, a star close to the reference star is input and the telescope computer allowed to move onto the star. The computer will show a position that is proportionately offset from the true object the farther

away the star is from the reference star as the mechanical parameters and refraction play an important part in precise position of the object. The telescope is moved by hand onto the object, the offset is stored for both axes in the computer for further modelling of the position algorithm. After a crude atmospheric model is applied for refraction, parameters are learned by the computer with more and more positions input and acquired, with their corrections stored in memory and added and interpolated for the next object.
The mathematics for this procedure calls for a coordinate transformation from the inclined coordinate (equatorial) system of the telescope to horizontal coordinates to have the respective alpha and delta coordinates transferred to azimuth and elevation. A button on the console labelled "offset correction" provides the computer with the necessary information to accept the data only when depressed by the operator.

3. In a more refined correction program, sensor data for temperature, humidity, and atmospheric pressure are correlated to arrive at a good refraction model and correction parameters for the mount with flexure components. This, however, will require some time to implement. As the year 2000 approaches, considering Input of the 2000 Epoch is investigated as soon as star catalogues reliable enough to warrant their use become available. At this time, the international standard remains the SAO Catalogue, with the RNGC for non-stellar objects forming the basis for calculation of stellar coordinates. Other sources can be the Messier Catalogue for easy to locate objects and classification of the object by name for demonstration purposes.

AUTOMATIC GUIDER

Guiding on the guide star can be done via hand operation from the hand panel, by computer automatically, or via an automatic closed loop guiding system that either locks onto a star (stars) or chops the light of a star to provide signals for the alpha and delta motors to correct for refraction and mount flexure online. Later systems will incorporate a CCD and allow even sub-pixel resolution (ref. JPL paper) for the guide star. With an automatic guider in place (mostly through the off-axis guider), the computer monitors the axis corrections for its modelling program for future positioning but does not interfere with the guiding decisions of the auto guider. Limit switches, of course, are activated as usual.

DOME AND SHUTTER

The shutter in Kuwait is a transverse opening twin-door shutter activated by a switch for opening and closure. There is no provision for partial opening of the doors.

The dome azimuth encoder provides information in absolute encoder values to an accuracy of one degree. The dome also has its rest position which is head on to the prevailing wind direction in order to avoid side pressure of the sand in a storm. The dome does not move continuously with the telescope but is only activated when the edge of the telescope is close to touching (line of sight) the westward shutter door. The azimuth position is also calculated during and previous to positioning of the telescope. Total revolutions of the dome are 720 degrees with a warning installed and displayed in the console at 650 degrees. The computer supervises this function during an observing run and adjusts the dome position accordingly. This may necessitate positioning of the dome before the telescope observing session can begin.

FOCUS POSITION

The focus position of the secondary mirrors is read and displayed with an accuracy of 1 in 2800 and 1 in 900 for the flat field Schmidt and the general purpose telescope (Kuwait), respectively. Focus travel is +/- 75 mm and +/- 23 mm (GPT and FFS) total, realized by two DC motors. They have limit switches that are overridden by reversal of direction. Focus position can be stored and correlated to observing instrumentation with temperature and humidity gradients (sensors) for retrieval of an exact focus position.

SENSORS

The sensors comprise temperature, humidity and pressure and are read periodically into the computer to provide information for modelling programs for refraction, mechanical flexure, image quality due to excessive gradients in temperature and humidity, sky condition, and focus position. The accuracy of the sensors is:

Temperature:	0.1 degree
Humidity:	1 percent
Pressure:	1 millibar.

CONCLUSION AND FUTURE OUTLOOK

A short overview of the complex structure of a telescope control system with a micro and mini computer has been given. This paper is to serve as a guideline for realising the telescope control for Kuwait and the 800 mm RC telescope at the Alterswil Observatory.

An outlook into the future will incorporate automatic guiding by a CCD or Vidicon / Saticon, recognition of position by locking onto stars in the field of view of the guider and recognizing the stellar field by the relative position of the stars to one another and displaying same on a monitor.

Colour monitors will provide all relevant information with colours associating to the degree of importance in the display (warnings in orange).