Algorithms to be implemented in the Antenna Control Unit

P. de Vicente

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Contents

1 Introduction

The ACU, Antenna Control Unit, for the 40M radiotelescope at the OAN is devoted to controlling the whole servosystem of the antenna and driving it to a given position which may change with time. It will also perform several operations related to the computation of astronomical ephemeris and the correction of errors in azimuth and elevation. The tracking of radiosources and the superposition of movements while tracking these sources can be acomplished either by providing azimuth/elevation tables and/or right ascention and declination tables dependent on time.

This document describes in detail the algorithms to be implemented in the ACU (Antenna Control Unit) for the coordinate conversion (ra/dec to az/el) and for the pointing and refraction corrections at the 40M dish and intends to be an agreed document where MAN can find them easily. All parameters needed by the algorithms will be supplied by the host computer (also known as RCC) or the LCC (Local Control Computer) using the commands described in the IDC document provided by MAN.

The LCC will need the atmospheric parameters and the refraction correction parameters. This information will be supplied upon request through the LAN using sockets. For this purpose the OAN will supply to MAN a network card that will allow the LCC to have two network cards. The atmospheric and refraction information will be supplied using one of these cards while the the other card will be used to comunicate with the ACU. We propose that MAN uses the former card also to transfer script files to the LCC.

The RCC will obtain the atmospheric parameters through the LAN using CORBA and requesting this information to a dedicated computer which logs the meteorological data and performs statistics with these data.

2 Time conversion

All transformations of celestial coordinates for astronomical purposes need to be done for a time scale called UT1. UT1 can be obtained from UTC (Universal Coordinated Time) by applying a small correction called DUT1. This correction is always smaller than 1 second, since UTC is always corrected to keep it within 0.9 seconds of UT1. The UTC is obtained by a GPS receiver, which broadcasts it using an IRIG-B signal or the NTP protocol through the LAN.

The DUT1 correction is variable and can be predicted several days in advance although the exact value is only known for past times. The DUT1 correction will be sent to the ACU using command 5.34 described in the IDC list.

UT1 is related to DUT1 and UTC as follows:

$$UT1 = UTC + DUT1 \tag{1}$$

Information relevant to these time scales can be found in `http://maia.usno.navy.mil/`. The announcements of future DUT1 values to be broadcasted in time signals are found in `http://hpiers.obspm.fr/iers/bul/buld/bulletind.dat`, while precise predictions of the UT1-UTC difference down to milliseconds are in `ftp://maia.usno.navy.mil/ser7/ser7.dat`.

3 Apparent equatorial coordinates to horizontal coordinates conversion

It should be made clear that equatorial apparent coordinates are different from equatorial coordinates for a given epoch, as for example J2000. Coordinates for a given epoch are suitable for compiling sources in catalogs since their position in this way is uniquely determined. Apparent coordinates are obtained by correcting the coordinates for a given epoch by proper motion, precession, nutation, aberration and figure of the Earth (if the sources belong to our solar system). All these computations will be performed in the RCC (or the LCC if the appropiate transformations are implemented there). Apparent equatorial coordinates can be considered constant for a whole day except for solar system bodies for which the equatorial coordinates have to be recomputed within a period of several hours. The equatorial apparent coordinates will be supplied to the ACU as parameters for commands 5.11 (Main drive program track command) and 5.12 (Main drive offset load command).

The transformation of coordinates between the apparent equatorial and local horizontal system needs the local sidereal time and the location of the observatory.

The local sideral time (LST) is obtained from the Greenwich sidereal time (GST) and the longitude of the observatory. To obtain the GST we need the GST at 0h of UT1, which we will call $GST0$. This time is provided to the ACU using command 5.34 described in the IDC list.

1. Greenwich sidereal time (GST):

   First we obtain the GST:

   $$GST = GST0 + UT1 \cdot 1.00273790935 \tag{2}$$

   The previous expression **should be computed using hours** or seconds of time (not arcseconds or degrees) as units. If GST is greater than 24 hours it has to be reduced so that the value is kept within the interval $[0, 24]$.

2. Local sidereal Time (LST):

   $$LST = GST0 + Long \tag{3}$$

   where $Long$ is the geodetic longitude of the observatory and it is considered positive towards the east of the Greenwich meridian. The Yebes observatory has a negative longitude. The current estimation for the geodetic position of the place where the azimuth axis of the 40M crosses with the plane that contains the elevation axis and is parallel to the ground:

   -3° 5’ 12.636” East   40° 31’ 28.814” North   991.977 m

The longitude is a parameter which is passed to the ACU together with latitude and height using command 5.16. We suggest command 5.16 accepts longitude and latitude in degrees, and height in meters. In order to use expression 3 the longitude should be expressed in hours. Conversion of longitude from degrees to hours is achieved by:

$$Long[\text{hours}] = Long[\text{degrees}]/15.0 \tag{4}$$

3. Hour angle (HA):

   The Hour Angle (HA) for a given radiosource can be calculated then from:

$$HA = LST - RA \tag{5}$$

   where RA is the right ascention of the source and it should be converted from degrees to hours as follows:

$$RA[\text{hours}] = RA[\text{degrees}]/15.0 \tag{6}$$

In the following trigonometric equations the arguments (HA, Dec, Lat) should be in radians:

$$\begin{aligned} HA\,[\text{radians}] &= HA\,[\text{hours}]\,0.2617993878 \\ Dec\,[\text{radians}] &= Dec\,[(\text{degrees}]\,0.01745329252 \\ RA\,[\text{radians}] &= Dec\,[(\text{degrees}]\,0.01745329252 \\ Lat\,[\text{radians}] &= Lat\,[(\text{degrees}]\,0.01745329252 \end{aligned}$$

If greater precission is needed the previous values may be obtained as stated in Table 1:

Numerical value	Using GNU C compiler (math.h)
0.2617993878	`const double HourToRad = M_PI / 12.`
0.01745329252	`const double DegToRad = M_PI / 180.`

Table 1: *Accurate conversion values between degrees and radians using GNU C*

Conversion from apparent Right Ascention (RA) and Declination (Dec) to Azimuth (Az) and Elevation (El) is performed as follows:

$$El = \arcsin(\sin Lat \sin Dec + \cos Lat \cos Dec \cos HA) \tag{7}$$

$$Az = \arccos\left(\frac{\sin Dec - \sin Lat \sin El}{\cos Lat \cos El}\right) \tag{8}$$

where azimuth is 0 towards the North and increases moving from the North towards the East as we look the observatory from above. Note that in C and C++:

$$\arcsin(x) \quad \epsilon \quad [-\pi/2, \pi/2] \tag{9}$$
$$\arccos(x) \quad \epsilon \quad [0, \pi] \tag{10}$$

To resolve the ambiguity in Azimuth one can use:

$$\text{if} \quad \sin HA > 0.0 \Rightarrow Az = 2\,\pi - Az \tag{11}$$

Right ascention and declination used in the previous formulae are apparent coordinates and correspond to the values passed using commands 5.11 and 5.12.

4 Pointing model

4.1 Foreword

Using a pointing model is a common practice among radiotelescopes devoted to astronomy to correct for mechanical missalignments. MAN provides for these missalignment errors a procedure which is summarized in Figure 1. According to that diagram the pointing model will be applied after other corrections which take into account gravity, readouts from the encoders and tables for the encoders are applied. This means that probably the pointing model will correct for very small values since the effects it takes into account will have been corrected previously.

The algorithm we propose is very similar to that used by ALMA (Mangum 2001) although we will add one more term for gravity, as in the 30M IRAM radiotelescope (Greve et al. 1996) and we will also take into account the missalignment of the Nasmyth mirrors (Barcia 2003). The latter produces errors which have the same dependency on azimuth and elevation as some classic ones like the constant offsets for azimuth and elevation, the tilt of the azimuth axis or gravitational effects, and therefore are not distinguishable from them. However this has no effect on the algorithm itself. We will use a similar notation as the one used for the 30M, instead of using the ALMA one.

Further information on the derivation of a pointing model for the 40M is available in Martín & de Vicente (2003).

4.2 Proposed algorithm

We propose the following algorithm for the pointing model:

$$\delta Az = P_1 - P_2 \sec El - P_3 \tan El - P_4 \cos Az \tan El + P_5 \sin Az \tan El \tag{12}$$
$$\delta El = P_4 \sin Az - P_5 \cos Az + P_7 + P_8 \cos El + P_9 \sin El \tag{13}$$

where both δAz and δEl have the same units as the P parameters. Usually these variables are expressed in arcsecs which is the order of magnitude of the correction. The P parameters

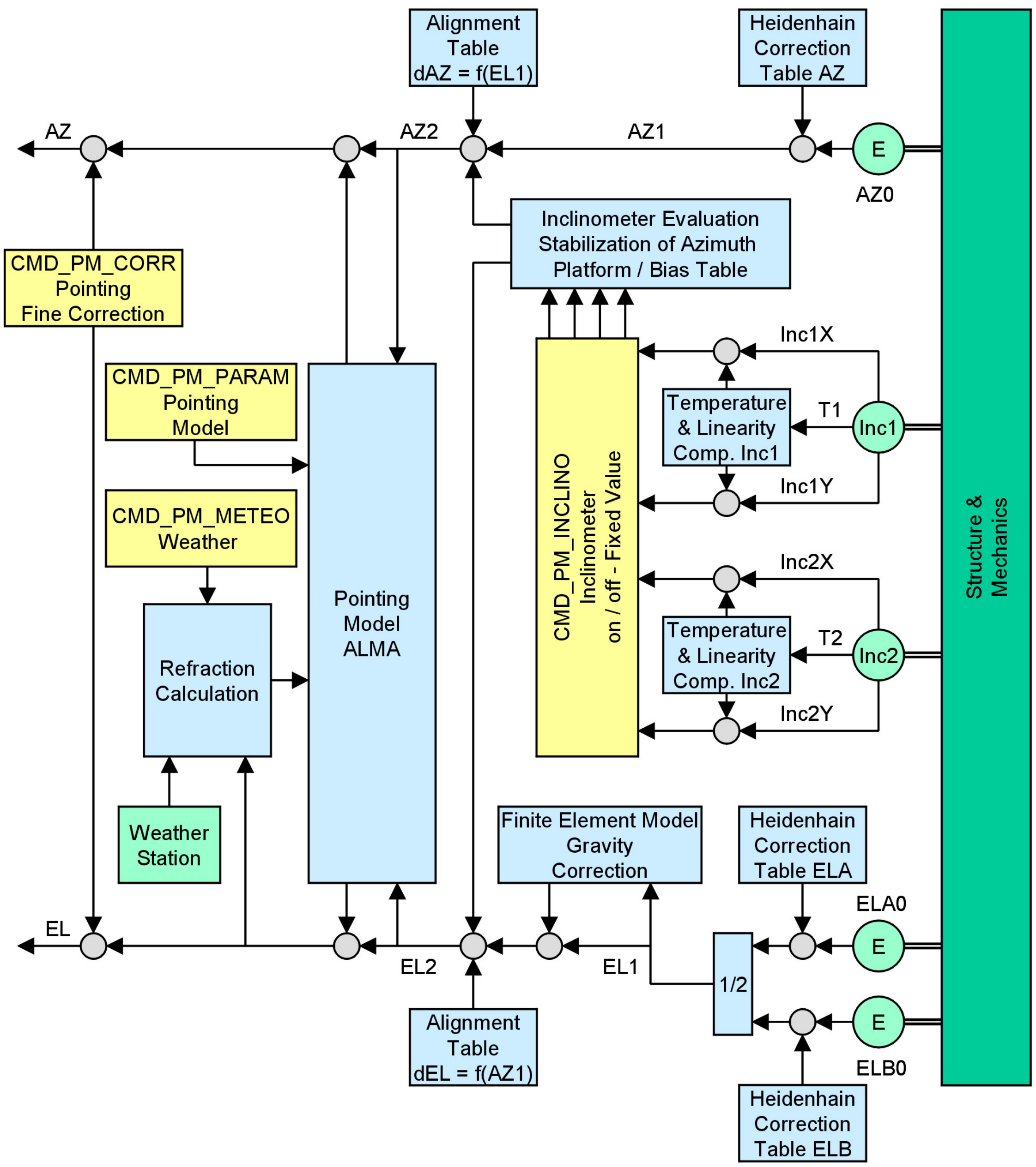

Figure 1: *Pointing correction block diagram proposed by MAN for the 40M dish*

are real numbers and therefore could be represented as a DOUBLE, but it is possible to save memory space by passing these parameters in units of milliarcseconds and using INT32 variables. Conversion from milliarcseconds to approppiate units should be performed within the ACU. To convert from degrees to radians use the conversion values shown in section 3.

P_1 is a constant offset which includes the azimuth encoder offset and a constant term due to the missalignment of the fixed Nasmyth mirrors.

P_2 is the collimation error. It is positive when the RF axis gets nearer to the North being the elevation axis along the North-South direction and negative when it gets farther from it. With cero collimation error the RF axis should lay along the East-West axis.

P_3 is a combination of two effects: the lack of orthogonality between the azimuth and elevation axis, and the missalignment of the Nasmyth fixed mirrors. P_3 coming from the lack of orthogonality is positive if the elevation axis gets close to the azimuth axis and negative if it gets far from the elevation angle. P_3 coming from the missalignment of the mirrors is always positive.

P_4 is the azimuth axis missalignment along an East-West axis. Positive if the axis is tilted towards the East and negative if tilted towards the West.

P_5 is the azimuth axis missalignment along a North-South axis. Positive if the axis is tilted towards the North and negative if tilted towards the South.

P_7 is a constant offset which includes the elevation offset and a constant term due to the missalignment of M3 and all the other Nasmyth mirrors.

P_8 is a combination of two effects: gravitational bending and missalignment of the Nasmyth fixed mirrors. If the term only comes from gravitational effects one would expect it to be positive since this error applies mainly to the subreflector which "falls" from its nominal position as elevation gets lower. Most of the bending should be due to the deformation of the tetrapod legs. This term might be positive and negative if the pointing error is corrected for a reference elevation smaller than 90 degrees. Below the correcting elevation it would be positive and negative over it.

P_9 is a combination of two effects: gravitational bending / homologous deformation and missalignment of the Nasmyth fixed mirrors. This gravitational part does not have a simple physical meaning for us, although it is used by the 30M dish and it is mentioned by von Hoerner & Wong (1975).

5 Refraction model

The algorithm to compute the correction due to refraction is only appliable to elevation. The parameters are passed using command 5.19 from the IDC list.

$$\delta El = R_0 \,\mathrm{abs}\left[\tan(90^\circ - El - \frac{B_1}{El + B_2})\right] \tag{14}$$

where El is the elevation and R_0, B_1 and B_2 are the parameters supplied in command 5.19. The units supplied in that command will be arcseconds for R_0 and degrees for B_1 and B_2.

The model used to compute the refraction correction is explained in detail by Pere Planesas (2003).

The refraction correction should be applied AFTER the pointing model correction has been applied.

6 Proposed parameters for some ACU commands

6.1 Command 5.34: Set DUT1

We propose this command changes its name to "Set DUT1 and TSG0" in the IDC list.

Data Format	Meaning
INT32	DUT1 (milliseconds) Range: ± 1000
UINT32	GST0 (milliseconds) Range: 0 - 86400000

Table 2: *Relevant parameters for setting DUT1 and the Greenwich sidereal time at 0h UT*

6.2 Command 5.19: Pointing Model meteorological data

We propose this command is renamed to "Refraction pointing correction", since we do not supply any meteorological data here. We just give three parameters to compute the pointing correction due to refraction.

Data Format	Meaning
UINT32	Refraction correction mode mode
DOUBLE	Parameter B1 [degrees] Range: 0 - 360
DOUBLE	Parameter B2 [degrees] Range: 0 - 360
DOUBLE	R0 [arcsecs] Range: ± 1296000.0

Table 3: *Relevant parameters for the refraction model*

6.3 Command 5.16: Pointing model parameter

We also propose to rename this command to "Pointing model" in the IDC list. We have added the position (longitude, latitude and height) of the 40M dish as parameters. It is also possible to create a new command to pass these parameters to the ACU but in order to avoid it we think that the "Pointing model" command can hold these parameters.

Data Format	Meaning
UINT32	Pointing model mode
DOUBLE	Geodetic Longitude of the antenna [degrees] $0 - 360.0$
DOUBLE	Geodetic Latitude of the antenna [degrees] ± 90.0
DOUBLE	Height of the antenna over the ellipsoid [meters] $0 - 8000.0$
INT32	P1 constant offset azimuth [marcsecs] Range: ± 648000000
INT32	P2 collimation error [marcsecs] Range: ± 648000000
INT32	P3 lack of orthogonality [marcsecs] Range: ± 648000000
INT32	P4 azimuth axis tilt E-W [marcsecs] Range: ± 648000000
INT32	P5 azimuth axis tilt N-S [marcsecs] Range: ± 648000000
INT32	P7 constant offset elevation [marcsecs] Range: ± 648000000
INT32	P8 gravitational $+$ mirrors term [marcsecs] Range: ± 648000000
INT32	P9 gravitational $+$ mirrors term [marcsecs] Range: ± 648000000

Table 4: *Relevant parameters for the pointing model*

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