A HISTORY OF AMATEUR ALT-AZ CIRCLES AND GO-TO DRIVES

(or, The Rime of the Ancient Celestial Navigator) by H.R. Suiter

Today, it has become common to find so-called "go-to" drive telescopes available at mega-stores, most of them being primarily intended for altitude-azimuth mode. I am old enough (and crotchety enough) to remember the first amateur efforts at fitting circles to alt-az mountings, and their necessary evolution into drive systems. I offer you a brief history, seen from one person's point of view.

First of all, the alt-az conversion is nothing new. It involves something called *spherical trigonometry*, which was worked out in the eighteenth century to be of use to maritime navigators. At the time, it was only useful for pre-computed tables, and required a great deal of data reduction even then. After many minutes, sometimes hours, of tedious hand computation, a navigator could tell a ship's location on the earth from the height of a star above the horizon and the time in Greenwich, England, which was carried in an accurate clock called a marine clock or chronometer. In astronomical computations, we are concerned with the inverse problem; we wish to compute the position angles of a star, knowing our location and the time.

However, the use of tables is much too slow, so the enabling technology for finding objects quickly with a set of alt-az setting circles is the programmable hand calculator. For the first time, we could go through the calculations in *real time*, and did not have to resort to tables. "Real time" is a name for a computation that can be done in time for when it is needed—on the fly. Thus, this calculation was not even possible for amateurs before around 1972, and it was really not possible until 1978 or 1979, with the advent of the Hewlett-Packard-41C calculator, to my mind the most perfect calculator ever made. It was neither too complicated nor too simple, and it could be fitted with a module that kept accurate time.

This is not going to be a mathematical discussion. Suffice it to say that the orientation of the celestial vault is describable by two angles. The commonest way of describing the sky is by the system Right Ascension and Declination, those two angles being (with minor differences) just the common Latitude/Longitude system projected out to the distant sky. The other way is by the so-called horizon coordinates, Altitude and Azimuth. Altitude goes from 0 degrees at the horizon to 90 degrees overhead, and azimuth goes from 0 degrees at north, to 90 degrees at the east, and so forth. The two angle system are different in that RA/Dec is attached to the stars and Alt/Az is attached to the earth. The way of changing coordinates from one to another is through something called the Euler transformation, worked out by Leonhard Euler in the middle of the 1700s.

Now even though the Alt/Az conversions and drives had been worked out for large radio telescopes years before (most optical telescopes were still equatorially mounted, but radio instruments had been led to alt-az by their great size), it had not yet percolated down to the amateur level. I don't know if it was popularized earlier, but I finally saw it in an *Astronomy* magazine article by Robert Burnham in 1978. (I believe it was not the *Celestial Handbook* Burnham, but another.) I wished I remembered it better. Also, later in 1979, a book was published by Peter Duffett-Smith, *Practical Astronomy With Your Calculator* giving, among other things, the algorithms necessary to make the angle conversions.

You wouldn't believe the complications involved in this "simple" coordinate transformation. For one thing, the given conversion applies for only one instant of time. As the earth turns it keeps messing up the coordinate match. For another, the earth is slowly wobbling like a top. This is called precession of the equinoxes. It doesn't mess up the calculations for one night, because the earth wobbles so slowly (the period of precession is around 26,000 years). It ruins the calculations because the listed stellar coordinates are only correct for one point in time. On the equator, it can induce an error of right ascension as large as 40 arcminutes, or bigger than the moon in the sky. Presently, the commonest coordinates are correct only for just after midnight 1 Jan 2000. The term for this is to say the coordinates are valid for *epoch* 2000.0.

Since the go-to drives presently used are almost sitting precisely on top of the epoch, they can use the 2000.0 coordinates unmodified and without accounting for precession. This is indeed a lucky break. Back in 1979, most of the coordinates were in epoch 1950.0, so they had to be precessed forward by 29 years.

Although I read Burnham's article, I never saw much detail about implementing it until a couple of articles appeared in *Telescope Making* #13 and #15, nominally in the fall of 1981 and partway into 1982 (TM wasn't too regular, then), by Stephen Kysor and Tom Dey respectively. Kysor wrote a little BASIC routine for the little TRS-80 pocket computer. Dey wrote his procedure for TI-59 or HP-67 calculators. Kysor used little 360-degree protractors as his circles and Dey used setting circles graphed on the accurate plotting machines that were making their first appearance just then. After this, I got inspired and I wrote a program for the HP-41C that used this algorithm. I implemented it in late 1982 on my 8-inch f/6 using (again) 360-degree protractors. I also included the effects of precession.

My little program used a 32-byte Euler transformation routine copied from Phil Fraundorf's as it appeared in *Calculator Tips & Routines, Especially for the HP41C/CV*, ed. by John Dearing. The program length of 32 bytes seems even shorter when you realize that a full Euler transformation consists of multiplying a 3x3 matrix times a position vector. Thirty-two bytes is shorter than the information contained in this sentence! Alas, in these days of bloatware filling whole CD-ROMs, efficient programming is a dying skill.

The first time I ever used this calculator and setting circle system, I was flabbergasted because it worked. Of course, it wasn't too convenient because I had to peer beneath the tube and at a dimly-lit protractor, but I was amazed nonetheless. I didn't call up the object name, as in the modern go-to systems, but put in the RA and Dec of the object in question. The HP-41 got the time from the internal clock module, and 11 seconds later I was presented with the altitude and azimuth. I then set the circles to read this value.

Later on, I tested the program under operational conditions during a Messier Marathon. I found 104 out of 110 objects, and only lost the rest because it was too bright outside when they were visible. The program had performed flawlessly all night. I did notice having to realign after GMT midnight and local midnight. My day number in each case had changed. For most purposes, though, I preferred to not use the circles. They were just too hard to read and set.

HP-41s were considered esoteric at the time, and they were a little expensive, so a friend and observing buddy in the next office of the Van de Graaff lab, John Kerns, wrote the equivalent routine for a little $40 Casio BASIC computer. He was very careful to order the steps properly to request the time last, so that the inevitable lag would have the least effect (the Casio had no internal clock, so you had to input that parameter, too). Also, he set the time about a minute ahead, so the setting time would be compensated for.

It was this program that was written about by Ohio observer Bill Burton in an *Astronomy Magazine* article in 1986. Bill had adapted illuminated Suunto inclinometers and compasses into a circle system that was held as high as your head and hence was easy to read. What had been a little weird and scary in 1981 was now suddenly popular and Bill, John, and *Astronomy Magazine* got dozens of requests for the program. (I was even referred a handful of requests for the HP-41 version!) It is this article that was mentioned in Appendix C *The Dobsonian Telescope*, by Dave Kriege and Richard Berry.

Now the method was receiving enough attention that it had become visible on corporate radar screens and was beginning to attract the notice of competent electrical engineers. In 1989, the necessity to squint at dimly-lit circles was obviated by adapting something called a shaft encoder to the finding system. A shaft encoder is a device that reports the precise angular relationship between two attachment points. I have read that this was first adapted to alt-az setting circles by a man named Rick McWilliams (though I have no knowledge of this stage of the development myself). He didn't sell this thing directly to the public, but marketed through other dealers. This explains the similarity of the units, and their relative ubiquity.

He also apparently wrote a much cleverer program. In previous versions, you had to level the 'scope, set the time/date, and the coordinates. Ideally, this would allow exact calculation, but you don't know the offsets in the circles. So the first thing you do is point at a star, calculate its position, and reset the circles to match the calculation. This new version has you set it on *two* stars, and you don't have to input the time or the position.

What additional parameters are set by the two new data? Well, assuming you still have leveled the scope, it will set the time and one of the two local coordinates, but it is insufficient to set them both. Why is this enough? Think for a moment. Longitude is intimately related to time, so it is possible to make an error in longitude and compensate it by another error in time. If you were to set on *three* stars, you could solve even for a non-leveled telescope. Another implication of this logic is that the only leveling that makes any difference is the north-south leveling, but I have never tested that. You could, by adding calibration stars, adapt a setting circle system for coordinate systems where the axes were not orthogonal.

These new shaft-encoder units were expensive, but anyone who used one had to have one. They didn't drive the telescope, but all you had to do was look at an LED display and zero two numbers as you moved the nose of the telescope around.

The next step was to adapt drives to do the job of moving the telescope. Note that this was different than the old job of equatorial drives, which was to follow the sky at a more-or-less constant rate. In these new finding systems, the shaft-encoder control unit reports an error to the drive system, and the drive system then acts to minimize that error. Once it has minimized that error, the drive system may then return to the old job of following the sky, this time by using both axes.

You could in principle slew to the object by using simple motors, but following the object in two axes cannot be readily done with the old-style synchronous motors. Those motors are really best operated at a fixed speed or a few fixed speeds. The trouble with an alt-az drive is that one drive or the other must slow to a crawl in some parts of the sky. For moving like that we need what are called *stepper motors*. A stepper motor receives a pulse of electricity and advances a fraction of a turn. If it must move fast it receives pulses at a high rate and if it has to run slowly it is sent a pulse only now and then. Generally, stepper motors used in astronomical drives are geared down so far that the pulsing is imperceptible. Another good thing about stepper motors is that the motor can slow down and give a small correction to the finding operation. You occasionally hear this correction as a form of "grunting" long after the obvious slewing is finished.

Stepper motors can even do the job (although less well) without using shaft encoders. If the pulse rate and the gearing are known very well, the system can keep track of where it is at by just counting the pulses. That's the way I suspect the low-end go-to drives like the Meade telescopes they sell in Wal-Mart work. Shaft encoders cost more than the 200 or 300 dollar baseline of these scopes

THE FUTURE

There is no reason that two additional technologies can't be added to alt-az drives. The first is some sort of digital inclinometer. Attach a couple of shaft encoders to a pendulum, and you would have a device capable of sensing errors in the leveling of the base. It could read these errors and figure them into the finding solution. The second is the Global Positioning System (GPS). Not only is the latitude and longitude given precisely, it also yields precise Universal time and the date. All the user would have to do is throw the thing on the ground, line it up on one or two stars to take out offsets, and punch up the object wanted next.