reduction in the overall distance. Would this be a simple matter to establish, and is it worth further discussion?

REFERENCE

[1] Tijardović, I. (1990). Trans-oceanic passages by rhumbline sailing. This *Journal*, **43**, 292.

KEY WORDS

1. Marine navigation. 2. Voyage planning.

Astro Without Azimuth

Charles Brown

Comments have been made on recent papers[1,2,3] which discussed a method of deriving an OP (observed position) from celestial observations, which does not depend upon the use of azimuth and intercept and which does not require a CP (chosen position) or DR position to be input into the calculation. Using the same principle, a method is given for calculating an OP where there has been observer movement between sights.

1. A DISCUSSION OF THE BASIC METHOD. The writer became interested in this topic in 1980 when applying similar thinking to radio bearings; subsequently the general principles evolved were applied to the determination of an OP from celestial observations.

A computer program using the Epson HX20 PC was evolved and has been in use since 1982/83. The method used is similar to that described by Spencer[2] and is based on the concept of great circles (GCs) pivoting about the GPs (geographical positions) and intersecting at distances equal to the ZD (zenith distance).

The solution for position is mathematically simple but laborious and depends almost exclusively upon the use of the spherical cosine equation. Resolution of the ambiguity in determined position(s) can be either automatic (e.g. using computed and observed ZDs for the third sight), manually or by reference to the retained DR. Any number of observations can be handled (depending on memory available) – the program automatically selecting pairs of sights from those available, together with the discriminating third sight.

The method used by the writer additionally employs automatic date/time recordings[5] at each observation; this enables the declination (DEC) and Greenwich Hour Angle (GHA) to be derived for each body from the internal almanac[4] (see Appendix 1).

The following comments refer to the basic concept outlined above and in references 1 and 2.

(a) The use of a third body to resolve ambiguity in position fails when all three bodies lie in the same GC, – an unlikely occurrence but it can exist, for example, when taking successive sights of the Sun when the zenith of that body lies near the equator; safeguards are built into the program.

(b) Narrow angle intersections (or virtual reciprocal bearings) can be a problem under certain practical conditions. For this reason, the angle subtended at the observer by each pair of bodies is output for examination.[7] Alternatively, selection/rejection can be controlled automatically. Note that it is a particular intersection and not the associated sights which is discarded.

(c) The latitude and longitude of each point of intersection can be output, on request, for manual plotting or VDU presentation and thus be available for examination by the navigator. Alternatively these data can be handled by any preferred mathematical procedure.

(d) As mentioned by Chiesa and Chiesa[1] the computed OP is as accurate as the observations permit it to be, unlike the intercept method, where the derived position is a function of the CP.

2. MOVEMENT BETWEEN OBSERVATIONS: COMPUTING A RUNNING FIX

2.1 *Correcting the DR/ZD.* Conventionally, when running between observations, the navigator will empirically compensate for apparent error in DR by moving it onto the nearest point on the current PL (Position Line), before continuing with the next 'leg'.

This procedure can be emulated mathematically as follows:

(a) Compute the ZD from the DR position and compare with the observed ZD

(b) Adjust the DR position according to the displacement found – towards or away from the GP (see Fig. 1).

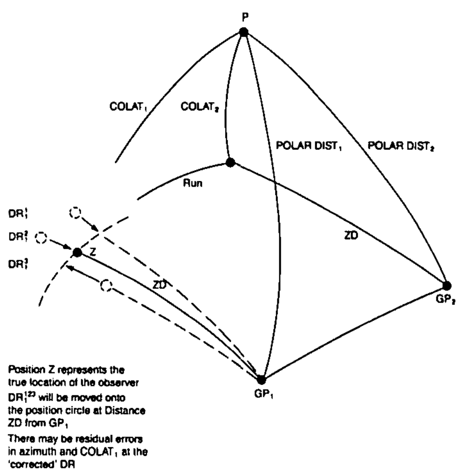

Fig. 1. Correction of zenith distance

Although this procedure yields a different DR, effectively it adjusts the ZD to the value found by observation.

Note: In using this procedure, unless the DR lies on the same GC to the body as does the actual position, there will be errors in azimuth and colatitude.

2.2. *Transferring the DR* This proceeds in the usual manner, starting from the corrected DR position.

2.3. *Transferring GPs.* The following is based on a spherical surface and on the simple principle of preserving the same juxtaposition (in azimuth and ZD) between DR and GP, at the transferred position, as existed at the time of observation.

The method has the additional advantage that the necessary algorithms are already *in-situ* in the basic program.

The procedure[6] (see Fig. 2) is as follows:

(a) Determine the angle Z(N) using:
COLAT$_1$ (corrected)

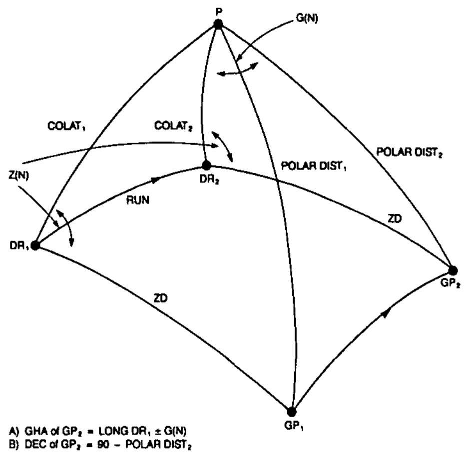

Fig. 2. Determination of transferred values of DEC and GHA

ZD
POLAR DIST$_1$

(b) Determine the side POLAR DIST$_2$ using:
COLAT$_2$
ZD
Z(N)
This yields the transferred DEC of the body.

(c) Determine the angle G(N) using:
COLAT$_2$
ZD
POLAR DIST$_2$
This yields the GHA (= LONG DR ± G(N)) of the body; the ambiguity in longitude is automatically resolved by reference to the vessel's direction of movement – see Fig. 3.

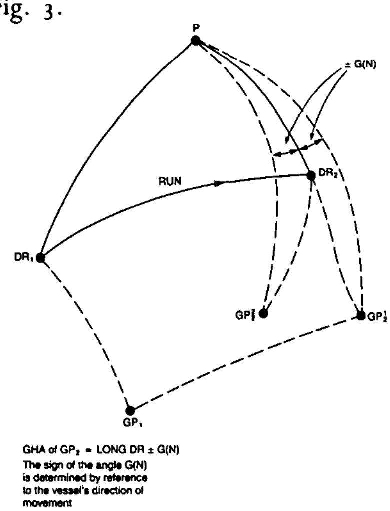

Fig. 3. Ambiguity in GHA determination

2.4 *Computing Position*. At this stage, each GP will have its unique values for DEC, GHA and ZD and these are all the data needed to compute for OP using the basic algorithms. GPs can be carried forward any number of times but the derived OP will, needless to say, reflect residual errors in DR.

Two examples are worked and results held by the Institute for inspection and comparison with published values[7]. The advantages of this approach to deriving a position, especially to the yachtsman, are obvious; the disadvantage equally so – an onboard computer is essential. The method was originally communicated to the Admiralty School of Navigation (HMS Mercury, Petersfield) in October 1983[8].

REFERENCES AND NOTES

[1] Chiesa, A. and Chiesa, R. (1990). A mathematical method of obtaining an astronomical vessel position. This *Journal*, **43**, 125.

[2] Spencer, B. (1990). Astronomical fixes without an assumed position. This *Journal*, **43**, 449.

[3] Williams, R. (1990). Computation of an astronomical running fix. This *Journal*, **43**, 444.

[4] Details of data sources for the internal almanac are with the R.I.N. (Appendix 1).

[5] Technical information needed for Auto Date/Time recording are with the R.I.N.

[6] A copy of the 'Ocean' Program (Print-out and Micro Cassette) is with the R.I.N.

[7] Two examples of this computation are with the R.I.N.

[8] Letter dated 27.10.83 from Lt Commander J. W. Pearson, HMS Mercury, Petersfield, Hants.

APPENDIX I

Data sources used in the compilation of the internal almanac

The following publications were used to compile the ALMANAC used in the EPSON HX20 PC. These publications were also the sources of the algorithms used to derive the DECLINATION and GHA of the SUN, MOON, 4 PLANETS and 59 STARS.

The ALMANAC is valid until the year 2000.

1 N.A.O. Technical Note No 46 published January 1978 and entitled 'Formulae for Computing Astronomical Data with Hand-held Computers' by B. D. Yallop and published by H.M. Nautical Almanac Office.
Used for: SUN – precision about ± 0·5
STARS – precision about ± 0·2

(2a) N.A.O. Technical Note No 46, Supplement, published December 1978 and entitled as above and again by B. D. Yallop.

(2b) Planetary and Lunar Coordinates for the years 1984–2000, pages 311–320, published by H.M.S.O. in conjunction with the Nautical Almanac Office – January 1983.
Used for: 4 PLANETS
Precision given

VENUS	± 0·1
MARS	± 0·6
JUPITER	± 0·6
SATURN	± 3·0

3 'Approximate Lunar Coordinates' by B. Emerson, published June 1979 by H.M. Nautical Almanac Office.
Used for: MOON – precision ± 1·0

The precision achieved in practice, when compared with values published in the Nautical Almanac, is usually much better than the maximum values given above.

Thus the GHA for SUN and STARS is usually within ± 0·2 and the inner PLANETS show a similar variation. The MOON and JUPITER are usually within ±0·4 of the published values but SATURN has been found to have discrepancy of as much as ±1·4.

To achieve the above accuracy, some mathematical functions, and especially those for the MOON and PLANETS, need to be computed to twelve significant figures.

The considerable help and guidance given by Dr B. D. Yallop of the Royal Greenwich Observatory in locating these sources of data and formulae, is gratefully acknowledged.

KEY WORDS

1. Astro. 2. Marine navigation. 3. Computers.