International Hydrographic Review, Monaco, LIX (2), July 1982

HYDROGRAPHERS OF THE WORLD, UNITE!

SOME THOUGHTS ON THE PROCESSING OF MULTIPLE POSITION LINES

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Paper also published in The Hydrographic Journal, No. 23, January 1982, U.K.

With all due respect to any hydrographers who may read this, for the purpose of this paper a hydrographer is defined as a person who entered the realm of offshore surveying via the crafts of the hydrographic surveyor and/or the navigator, the latter term being used in its traditional sense of 'one who controls and directs the progress of a ship' rather than the modern American connotation of 'one who reads the dials of a radio positioning receiver'. The term craft is used to denote the practical application of art and science; requiring skill, experience and judgement on the part of the practitioner – professionalism is another matter, more related to responsibility, but in many professions it is first necessary to be a good craftsman.

When the oil industry first entered the North Sea the early survey work was largely carried out by hydrographers, being at that time the only offshore surveyors available, but the supply was limited. Today the dominant discipline might be described as that of the Geodesist. The term Geodesist is used to include both those who are geodesists – and therefore scientists, not craftsmen – in their own right, and those land surveyors who have a degree in land survey, a relatively recent phenomenon. Now the land surveyor must also be a craftsman, as earlier defined, but European Universities do not teach crafts – nor indeed does it take three or four years to teach the techniques of land survey – and so a large part of their course consists of geodesy and statistics.

These latter are valuable sciences but they are ones with which the hydrographer may have only a nodding acquaintance. He is aware of the principles of least squares adjustment, for example, but may well have never carried one out, since the standard of triangulation necessary in the past for hydrographic control was rarely higher than Third Order, for which simpler methods were adequate and more cost

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effective. When the conversation turns to 'co-variance matrices' and the like, therefore, particularly if he is of an older generation, the hydrodrapher's eyes glaze over and he becomes rather quiet. He is prepared to believe that they are a good thing but he is not sure that he would recognise one if he saw one. So far so good, but, the reader may ask, so what? The point is that different backgrounds lead to different mental attitudes and different approaches to the same problem – such as that of offshore positioning. At this moment the Geodesist view holds sway in the North Sea and is threatening to spread; the time is therefore ripe to point out that this is not the only approach, and that a case can be made to suggest that while it may be appropriate for the North Sea it is not necessarily the answer in other parts of the world.

The particular problem at issue is the treatment of multiple position lines; a relatively new problem since only recently have more than two position lines become generally available. The land surveyor has always looked askance at the hydrographer's willingness to use only two position lines to determine his position – an unacceptable procedure, and quite rightly so, in land survey. What was not always appreciated, however, was the difference between the two situations. Two plane table stations might be separated by 30 minutes in time and a mile or more of climbing a mountain, cutting through bush or wading through swamp; consecutive sextant fixes, however, were only a minute or two apart in time, during which period the vessel was proceeding along a known course and normally at a constant speed. The experienced hydrographer knew at once if he was attempting to plot an erroneous angle or if he was experiencing a throw-off when he changed fix. Thus when the early radio positioning systems were introduced, he was comfortable with the fact that they only displayed two ranges or two hyperbolic values, and he merely adjusted his checking procedures to ensure that errors and blunders were detected. Today, however, not only are multiple ranges available from a single receiver, but it is commonplace to use two or more radio systems simultaneously, so that a true multiplicity of position lines (or LOPs to follow the American usage for brevity) is often available; and, furthermore, with a shipboard computer it becomes feasible to make use of all this data in real time. The question then becomes how best to program the computer to make proper use of the information available.

The Geodesist approach has been to use the standard land survey technique for reconciling multiple LOPs and to determine the most probable position by the method of least squares (*). This was easy to accomplish, since modern desktop computers are well suited to matrix manipulation, and it has certain undeniable advantages: the least squares solution requires a minimum of participation by the shipboard operator, it gives an indication of fix quality, and the resulting track on the plotter is considerably smoother than that provided by the raw data. A problem, however, arises when more than one positioning system is available; different systems have different error characteristics and need appropriate weights to be applied if the least squares solution is to be valid. These weights can be estimated reasonably well after the fact by studying propagation paths and monitor records,

(*) In passing, let it be noted that, in balancing a triangulation, least squares are used only after considerable pains have been taken to eliminate or reduce both random and systematic errors by multiple observations on opposite faces, using different parts of the circle, etc.

but their estimation in real time requires a degree of subjective judgment that is unacceptable. For this reason it is accepted in the North Sea that the least squares solution should only be applied to data from a single positioning system, with unit weight applied to each LOP. The inference has, however, been drawn from this that 'it is bad survey practice to use LOPs from different sources to determine one's position', and this impression seems to be widespread. To the navigator, however – and paraphrasing Miss Gertrude Stein – a position line is a position line and it matters not from whence it comes. If a ship sights an isolated lighthouse, the ship's position will be determined by a radar range combined with a visual bearing – since a visual bearing is more accurate than a radar bearing – and any brave soul who has the temerity to suggest to the Captain that this is an improper procedure must expect to find himself off the Bridge. A more correct statement surely is that 'it is bad survey practice to use a least squares solution in real time, when the LOPs are derived from different sources'. This restriction of LOPs to those provided by a single positioning system, in order to allow the least squares solution to be used, may however provide a less accurate fix than a hybrid fix, based on different positioning systems. There are often situations in which the maximum angle of cut between the LOPs of System A might be 40°, that of System B only 25°, yet lines from A and B will intersect at 70°.

There is another criticism of the current vogue for least squares. There has been much esoteric debate on the application of statistics to filtering and fix computation, and the uninitiated can hardly be criticised for believing that if their computer performs these mathematical gyrations the resulting co-ordinates do indeed represent the most probable position. This however is a fallacious assumption, even if the intersections between the LOPs are the best available. It is suggested that statistics can only address one part of the problem and that this concentration on statistical technique is causing the other – and frequently more significant – parts to be neglected. The fundamental problem is one of removing error from observations, and to the hydrographer the traditional division of errors into random errors, systematic errors and blunders has more meaning than the modern vogue for 'bias' and 'noise' (particularly when the latter is further qualified as 'white noise' or 'coloured noise'). Of the three categories of error only random errors follow the laws of probability and in general only these errors can be reduced by statistical methods. These errors, however, are by far the least significant in conducting a survey. If positioning data contains random error only, the left/right indicator will be difficult to follow and the track plot will be unaesthetic, but post editing will allow an accurate chart to be submitted to the client. An unsuspected blunder or systematic error, however, may make the whole survey valueless – and in some circumstances extremely costly to the client.

It is suggested therefore that where redundant positioning data is available, the primary function of the computer program should be to assist in determining systematic error and to reveal the existence of blunders at the first opportunity – not to reconcile all the data so that the existence of either error is masked and its subsequent correction made more difficult. The method proposed is to allow the surveyor to select the Two Best Lines (the TBL solution) to compute the vessel's position, and to print out at each fix the distance of this position from each of the other LOPs. It is desirable that these distances be available both in feet or meters and in receiver units – lanes or micro-seconds, say – since the former value gives a

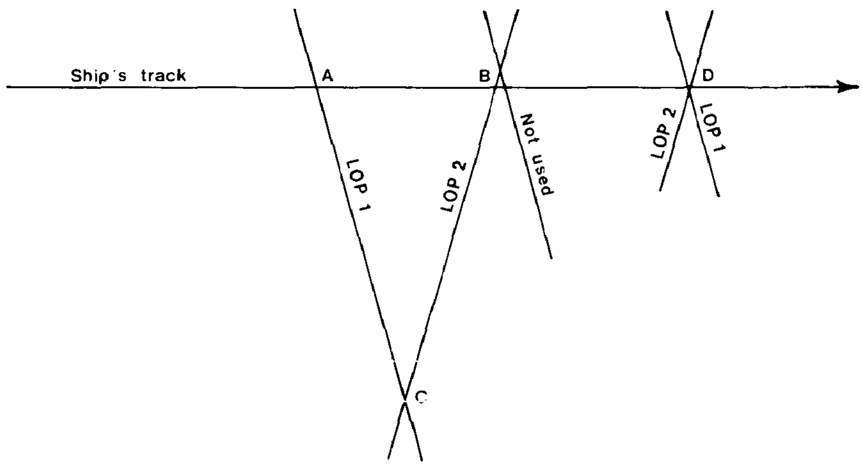

Diagram 1

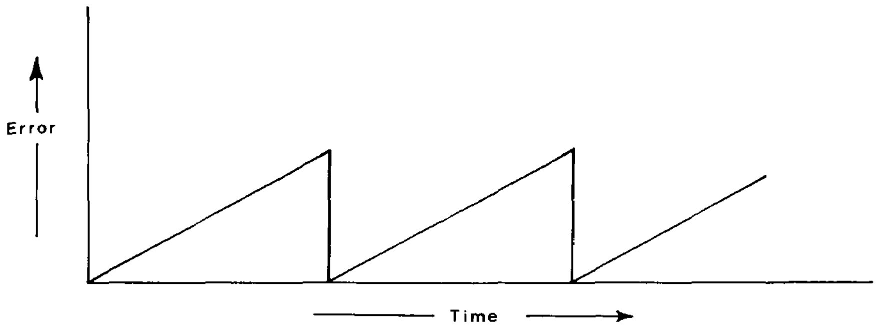

Diagram 2

direct indication of fix quality while the latter gives the calibration correction. This facility for continuous calibration enables greater use to be made of navigational systems such as Loran-C, which have adequate repeatability for many purposes but which are, in survey terms, uncalibrated. Thus, during daylight hours, primary positioning might be by a 2 MHz system such as Argo – during which time the systematic error of the Loran-C would be observed and corrected – so that, after dark, work could continue on Loran-C when skywave made the Argo unusable.

The use of the hybrid fix itself contains a source of systematic error which may not be generally appreciated. If the computer is programmed to read LOP 1 and 2 in succession and to compute position as soon as LOP 2 has been read, situations will arise similar to that in diagram 1, where LOP 1 is read when the ship is at A and LOP 2 when the ship is at B, so that the computed position of the vessel is C. If each positioning system outputs data once a second, the maximum length of AB is the distance that the ship can travel in 999 milliseconds, say 20 feet or 6 meters at 12 knots. If the position lines cut at 30° the maximum distance of C from AB – the maximum systematic error – becomes 37 feet or 11.2 meters, a figure that will be unacceptable for many purposes. This error is rarely a constant but varies in an unusual way, being dependent on the relative timing of the clocks which control the two positioning systems. In the example, the maximum error occurs when LOP 2 is output 999 msec later than LOP 1. If Receiver 2 is cycling more slowly than Receiver 1, it could happen that on the next interrogation Receiver 2 outputs 1001 msec after Receiver 1, which has in the meantime output another piece of data, so that, at D, LOP 1 is in fact read immediately before LOP 2 and the error drops to zero. Thus, over a period of time, the error pattern looks like diagram 2, where the maximum error is dependent on the speed of the vessel, the angle of cut of the position lines and the period between outputs, while the time between each sawtooth will normally be a matter of hours, dependent on the relative timing of the two systems.

This is not an error which can be removed by statistics, nor indeed by any form of post-processing; it must either be prevented from occurring or it must be corrected in real time. It can be prevented from occurring by making the computer control the system and thereby ensure that Receiver 2 is read immediately after Receiver 1. This, however, is only successful if the act of interrogation triggers the range measurement, but this is rarely the case. More typically, the data output by the position receiver will be that most recently measured, which might be up to 1 second stale, so nothing has been gained. It is suggested, therefore, that the preferable procedure is to make use of the multi-priority level facility of a modern computer, in conjunction with a real time clock that can record relative time to an accuracy of at least 100 msec. The clock can be either in the computer or in a separate sensor interface box. The procedure then is that, as soon as a sensor indicates that data is available, the computer drops what it is doing, reads the data and timetags it to the nearest 0.1 second before returning to its previous task. As a further refinement, the program should allow a correction to be applied to the timetag, to cover the situation where a ranging system measures four ranges in succession, each measurement taking 100 msec, say, and then outputs all four simultaneously.

With timetags of this type, it becomes a simple task for the computer to interpolate all the position data to a common point in time and then to re-order the raw data into chronological sequence with the computed position, to facilitate offline processing. The whole procedure then becomes:

a) Smooth or filter the raw data to reduce random errors. This is the area where statistical techniques can be helpful and Kalman type filters will do much to reduce these errors in real time. However, as an alternative, favoured by proponents of the KISS (*) school – and only possible when LOPs are received at regular intervals – is a mean of, say, 7 consecutive values, to give a meaned LOP value for a time 3 seconds earlier. There is little problem for the computer in maintaining chronological sequence, if all the data is timetagged, and, from the point of view of steering guidance, a three second delay is trivial when compared with the time taken to plot by hand a sextant fix. Whichever method is used, it is necessary first to discard, by comparison with a prediction, the wild ranges that are sometimes experienced with certain categories of positioning system.

b) Interpolate all LOP's to the same instant of time.

(*) Keep It Simple, Stupid !

c) Compute the x-y position from the Two Best Lines (selected previously after considering angle of cut, sensitivity and stability) and use this position to update the Helmsman's Display and the track plot. Display, and print at each fix, the distance of the computed position from each of the other LOPs. These distances, in receiver units, are in fact the familiar C – O corrections that must be applied to 2 MHz systems – if the system(s) used to provide the Two Best Lines is itself correctly calibrated.

d) Record both the raw data and the computed position, in chronological sequence. If subsequent analysis shows that the C – O values used gave acceptable accuracy, then no further position processing need be done. If on the other hand the highest accuracy is desired – possibly only for some part of the data that has special significance – then appropriate corrections should be determined for each LOP, considering both the constant element and the range dependent element; weights, based on the random error of each LOP, should be applied; and then a least squares adjustment carried out.

If the above approach is accepted a further benefit will follow which is particularly significant in hydrographic work. Current least squares solutions take 2 to 15 seconds to process three LOPs on a desktop computer, depending on the algorithm used. This makes it difficult to handle 10 depth measurements a second without making position calculation unacceptably slow – but if the computer does not look at every depth the accuracy of depth selection is inevitably reduced. The computing load of the TBL solution, however, is considerably less and can be divided into a Foreground portion, computed at high priority, and a Background portion which is worked on whenever the computer has nothing else to do. In background the program starts from an Estimated Position and computes the value of each LOP and three constants that depend on the direction and lane-width of the position line at that point. Then in foreground it only takes one or two hundred milliseconds, depending on the number of LOPs, to determine position relative to the E.P. and the apparent error of the remaining position lines. With this approach it is of course necessary to ensure that the background computation is repeated often enough to prevent the curvature of the position lines from introducing a significant error.

It is recognized that there is an apparent disadvantage to the method proposed in that it requires a greater degree of judgment aboard the ship. The hydrographer would hardly see this as a disadvantage since he still distrusts the computer and would like to keep a measure of control over what it does. More importantly, he has the knowledge and experience to make the correct decisions from the information presented, but it will perhaps be argued that many of those currently operating computer based systems in the commercial side of the industry do not have this background. It is easy, however, to denigrate the abilities of those who are younger, less experienced and possibly with a lesser technical education than ourselves; if we were to give more time to training and personnel development – and less to the development of sophisticated computer programs and electronic wizardry – we might be surprised at the results.