Article

Verification of the Z-Component in the RTK Survey of Drogden Channel

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Abstract

The object of this investigation is to detect the presence of long-term blunders in the vertical component of a hydrographic survey, as e.g. cycle slips in the real-time kinematic GPS system or biases in the tide correction of the tracks. To this end the paper proceeds along two tracks: A visual, subjective one, where the contributions of a track to a DTM is inspected interactively, and an objective one, based on the method of least squares, where the tracks of the survey are construed as nodes in a leveling network.

Résumé

Cette investigation a pour objet de détecter la présence d'erreurs de longue durée dans la composante verticale d'un levé hydrographique, comme par exemple les petites erreurs de cycle dans le système GPS cinématique en temps réel ou les biais dans les corrections de marées des profils de sonde. Dans cette perspective, l'article contient les deux approches suivantes:

D'une part, une approche visuelle et donc subjective, dans laquelle la contribution d'un profil de sonde à un modèle numérique de terrain est examinée, et d'autre part une approche objective, reposant sur la méthode des moindres carrés, où les profils de sonde du levé sont représentés aux nœuds sur un réseau de nivellement.

Resumen

El objeto de esta investigación es detectar la presencia de errores a largo plazo en la componente vertical del levantamiento hidrográfico, como pe. los niveles del ciclo del sistema GPS cinemático en tiempo real o las distorsiones en la corrección de mareas de las derrotas. Con esta finalidad, el artículo se desarrolla en dos líneas:

una visual, subjetiva, en el que las contribuciones de una derrota a un DTM se inspeccionan de forma interactiva, y una objetiva, basada en el método de los cuadrados mínimos, en el que las derrotas del levantamiento se construyen como nudos en una red de nivelación.

Introduction

A Real-Time Kinematic (RTK) GPS system is an attractive complement to the heave sensor in hydrographic surveys. Together the two sensors offer absolute control of the Z-component of the reference position of the vessel, and yield the water level after a correction for geoidal height and compensation for antennae offsets, remote heave and the setting of the vessel at the time of measurement. The data acquisition software from EIVA offers a display of a pseudo water level, computed as the water level but uncorrected for the vessels squat. In the Royal Danish Administration of Navigation and Hydrography (RDANH), this pseudo water level is monitored during RTK surveys in order to detect cycle slips.

Table 1 depicts the average pseudo water level for four tracks measured 14 August 2002 between 07:02 and 08:34 where the last track stopped. Inspection of the pseudo water level for tracks measured later that day confirms that the water level of –11cm is correct, so it follows that after a GPS blunder the system maintained an artificial shift in the pseudo water level by 15cm for more than one hour. Other similar incidents from the survey of Drogden channel confirm that the GPS blunders follow a common pattern where the pseudo water level is changed for an extended period of time, before returning to its original level.

File Name	Average Pseudo Water Level	Least Squares Estimate of Offset
0-2_0214aug070225_068	-24 cm	17 cm
0-2_0214aug071919_069	-26 cm	19 cm
0-2_0214aug074000_070	-28 cm	18 cm
0-2_0214aug081112_071	-11 cm	2 cm

Table 1: Cycle slip sampled by O-boat 02 at 14 August 2002

An idea that immediately suggests itself is that this pattern may repeat itself without being detected, if the blunders are small, i.e. disappear in the noise introduced by the waves. Furthermore, in shallow waters a minor change in the water level may be explained away as a 'build up' caused by changes in the speed or direction of the wind. In Drogden channel such build-ups are common, so the display of the pseudo water level cannot be expected to discriminate blunders of, say, 10cm or less.

A trivial, but important, test of a RTK GPS system is to log a set of time series sampled at survey frequency for different transmit distances, while keeping the receiver in a fixed position. For hydrographic surveys the time series of the Z-component is of special interest, because the cost of a survey is optimised by reducing its error budget (Hare, 1995). The data sheet for the Ashtech Z12™ claims a standard deviation of 1.7cm for the vertical component for static measurements, but it does not state that measurements sampled within short time spans are correlated. Furthermore, under survey conditions the performance of the Ashtech Z12™ degrades to a standard deviation of 5cm – according to the data sheet. This change in performance as well as the autocorrelation is probably due to the use of two different filters, one for static measurements and the other for ship movements. There is no reason to expect that the autocorrelation of the time series performs any better under survey conditions than for static measurements; worse, if anything, causing the vertical component of the track to undulate with respect to its true position.

In the RDANH RTK measurements are sampled once every second and the recommended speed for hydrographic surveys is 6 knots. It follows, that for sizable portions of the track the Z-component may be biased, so that the error budget has to be adjusted accordingly.

Above two examples of temporary biases of the Z-component have been presented. For hydrographic surveys they are by no means unique. Other examples are tidal corrections for non-RTK surveys, and unrecorded fluctuations in the velocity of sound, just to mention a few.

This paper presents a method, which, during post-processing, enables the surveyor, in a systematic way, visually to inspect areas of the survey which are affected by biases in the Z-component, and to estimate the size of these biases, using the principle of least squares. The survey of Drogden channel is used as a case study, not because of the biases which actually were found, but rather to demonstrate the precision of the method.

The first step is to embed the observations of the survey into a digital terrain model.

The DTM

Areas of the seabed covered more than once during the survey provide a way to check the Z-component. One way to compare different tracks covering the same area – and indeed the way used throughout in this paper - is to embed the geo-positioned depths into a fixed DTM grid. By doing that, each track T_i is in a natural way associated an area V_i, consisting of the union of all cells in the grid, which contain at least one observation from the track. Areas of intersection $V_i \cap V_j$ of tracks T_i and T_j may then be inspected visually in the DTM or used to estimate a bias in the Z-component between the two tracks.

In the case of the survey of Drogden channel, the post-processed depths were placed in a DTM with a grid resolution of 1m adhering to the following rule: Each cell in the DTM was assigned the minimum depth of all the depths in the survey positioned inside the cell, together with an identifier of its track. This technique allows the set of cells U_i contributed to the DTM from each track T_i to be visualized. Notice that the minimum depth is used to define the depth of each cell at this point. The reason for this is that hydrography traditionally is concerned with ship safety. Below, when estimates of the depth difference between neighboring tracks are found, average depths in each cell are used.

Now, in order to get an idea of what to expect, when the area where two neighboring tracks overlap is inspected, it seems natural to investigate the ideal case where the sea bed is flat and the tracks in the survey are parallel and only intersect with the outermost beams.

A Theoretical Model

Suppose that the overlapping zone $V_1 \cap V_2$ between two neighboring, parallel tracks T_1 and T_2 surveyed in a level area is inspected. In order to get an idea of how the two tracks blend in the DTM, random drawings from two normal distributions N(0,1.5) and N(0,1), both with mean zero, but with different standard deviations, have been used to estimate the probability that an observation from track T_1 is selected in the DTM, for a cell containing various combinations of beams at, say, 60°~N(0,1.5) from track T_1 and beams at 50°~N(0,1) from track T_2. Table 2 depicts the outcome of this experiment.

The cell contains:	1 beam from T_2	2 beams from T_2	3 beams from T_2	4 beams from T_2
1 beam from T_1	0.5	0.37	0.31	0.26
2 beams from T_1	0.70	0.58	0.49	0.44

Table 2: Probabilities that the minimum depth in the DTM belongs to T1

Whenever there are just two measurements – one from each track – in a cell, then the probability that the minimum depth belongs to track T_1 is ½, irrespective of the standard deviation of the two depths. Whenever more than one depth from the same track occupies a cell, however, both the standard deviation and the number of depths have to be taken into account, when the probability is determined. Therefore the pattern of interlacement between neighboring tracks depends on the cell size, making it difficult to draw any inferences from it. When a bias is present, however, it's another matter. Figure 1 depicts a regular pattern where outer beams dominate in the intersections of the tracks, corresponding to the situation where the sea bed is smiling.

Figure 1: 'Smiling' sea bed exposed by the visual approach

When the number of cells in the intersection on both sides of the centre line between the two tracks is the same, a simple count may be useful. Let t_i and t_j be the number of cells in $V_i \cap V_j$ belonging to t_i and t_j respectively. Then, due to the symmetry around the centre line of the two tracks and under the above assumptions, t_i (and t_j) will follow a binomial distribution bin (t_i+t_j ,½). A famous theorem by De Moivre-Laplace then states, that as t_i+t_j increase, the probability of getting ti or fewer cells converges to $\Phi\left(\frac{t_i - t_j}{\sqrt{t_i + t_j}}\right)$ where Φ() is the cumulative normal distribution function. In practice, a seabed is never level, of course, but the argument can be seen to hold for subsets of the seabed which, on average, are level.

Now, the quotient $u_{ij} = \frac{t_i - t_j}{\sqrt{t_i + t_j}}$ determines, via the cumulative normal distribution Φ() the probability of getting the number of cells t_i and t_j belonging to the intersection $V_i \cap V_j$ of the two tracks to T_i and T_i, or any distribution of t_i and t_i which is worse. This holds true if the probability of getting the smallest depth is the same for T_i and T_i, for any cell. For a flat sea bed and for parallel overlapping tracks this holds true too, as explained above. For a survey, this model does not hold when three or more tracks cover the same area, but in hydrographic surveys such areas are kept at a minimum, so the influence is ignored in the following. In this way a quotient u_i is attached to any track T_i with respect to the remaining part of the survey. When the numerical value of u_i increases the probability that the model holds true diminishes, as indeed it must when neighboring tracks are shifted vertically with respect to each other. So, other things being equal a sorted list of quotients presents a key to tracks which should be inspected visually for a bias in the Z-component.

The Survey

Drogden channel is situated in the southern part of the Sound, the narrow strait separating Denmark and Sweden. The survey covered an area of 3 km x 15km surrounding the channel with depths between 2 and 19 metres, and the channel itself, which with a guaranteed minimum depth of 8m bounds the draught of vessels passing through the Sound. The survey was conducted by the RDANH from May to October 2002, only discontinued by a 3 weeks summer vacation. A total of 2578 different tracks were surveyed by two O-boats, O1 and O2. An O-boat is a small trimaran, 8.45 x 2.52m, powered by two diesel outboard motors. O1 and O2 are identically equipped with Odom online s/v mounted at the transducer, Reson SeaBat 8101, POS MV™ and Ashtech Z12™. RTK was employed throughout with PDOP<4, the ambiguity level was set to 99% and the elevation mask fixed at 10° for the receiver and 15° for the transmitter. The position of the reference station was fixed during the survey and the distance to the rover was always less than 10km. In order to introduce some measure of control with systematic errors, it was decided in any area, only to survey every second track in one day's work and then fill in the gaps later. EIVA's software was used during data capture and later on to edit the raw sensor data. Further post-processing was carried out with in-house developed software.

Below, depth measurements from the survey are used to estimate biases in the Z-component of the surveyed tracks. Therefore, fluctuations in the velocity of sound in the water (s/v) during the survey of a track relative to the measured s/v profile also enter into the equation. In the survey of Drogden the s/v at the transducer was sampled once a second by direct measurements, while s/v profiles were measured at the surveyors' discretion by indirect measurements, i.e. temperature and conductivity. This procedure offers control of Snell's constant, which is important in order to avoid a bias in the ray tracing when the path of the echo sounders ping through the water column is calculated. A further benefit is, that for small relative changes in the s/v, the Z-component of a swath is transformed according to the formula (Eeg, 1999)

$$\Delta z = d \cdot \bar{\rho} \cdot \left(1 - \tan^2 \theta\right)$$

where d is the distance (along the plumb line) from the transducer to the sea bed, $\bar{\rho}$ the average relative change of the s/v in the water column and the angle θ is measured relative to the Nadir. Change parameters in the above expression according to $x = d\tan\theta$, then the section of a flat sea bed covered by the angular sector ±60° is the interval [-d√3, d√3]. From the fact that

$$\int_{\theta=-60^0}^{\theta=60^0} \Delta z \cdot dx = \frac{\bar{\rho}}{d} \int_{-d\sqrt{3}}^{d\sqrt{3}} \left(d^2 - x^2\right) dx = 0$$

results, that for a flat sea bed the average bias in each swath covering this angular sector is zero. In the survey of Drogden, a swath width of ±60° was used throughout, except for the channel itself, where the swath width was confined to the interval ±45°. Consequently, the average bias caused by s/v errors can be expected to be small for the main part of the tracks in the survey.

The Visual Approach

The observed geo-positioned depths were placed in a DTM with a grid resolution of 1 metre complying with the rules laid down above. Then, for each track T_i the number m_i of cells in the set $V_i \mathrm{I} \left[\bigcup_{j=1}^{2578,\, j \neq i} V_j \right]$ was calculated, together with the number $n_i \leq m_i$ of these cells also belonging to U_i. The tracks were then sorted by the quotient $|u_i| = \frac{|2n_i - m_i|}{\sqrt{m_i}}$ yielding a list of tracks, which were submerged or elevated with respect to the surroundings. Figure 2 depicts the whole survey, where each track has been assigned its own grey tone. A box indicates the boundary of a zoom window which itself contains a box corresponding to yet another zoom window. In the zoom windows a cursor points at a track submerged relative to its neighbours.

While the situation depicted in Figure 2 is extreme, it was at once apparent from the size of the quotients, that the n_i did not adhere to a bin(m_i ,½) distribution – which they strictly speaking should not because some of the areas were covered by more than two tracks. Nevertheless, the quotient proved to be a useful tool to single out areas of interest for visual inspection.

A word of warning may be appropriate at this point. A track may seem to be displaced vertically without really being so. A horizontal displacement may cause the same effect on a slope and the position of seaweed in the water column depends on the current, thus confounding the issue when present.

The visual inspection was supplemented by pooled estimates of the vertical distance between tracks and their neighbours, in order to somewhat compensate for the subjectivity of the method. It soon turned out, however, that there was a need for a complementary method, because gross errors in the Z-component tended to be constant and extend over several tracks in a row. This muddles the picture somewhat and makes it difficult to pinpoint the location of a blunder.

The Analytical Approach

While the visual approach makes use of the tracks and their intersections, we now consider the dual of a multibeam survey, i.e. a leveling network, where the pair (tracks, intersections) is construed as (nodes, observation of depth differences between the nodes). Notice that a consequence of construing the tracks as nodes in a leveling network is that the along track variation of the Z-component is ignored and only the average vertical displacement is investigated.

The observations of the leveling network are found by the following procedure: The areas of intersection $V_i \cap V_j$ of any two tracks T_i and T_j give rise to two DTMs, this time constructed by averaging the depths in each cell. Differences between homologous cells in the two DTMs then produce a set of estimates of the difference in level between the two tracks, which then can be pooled to yield a

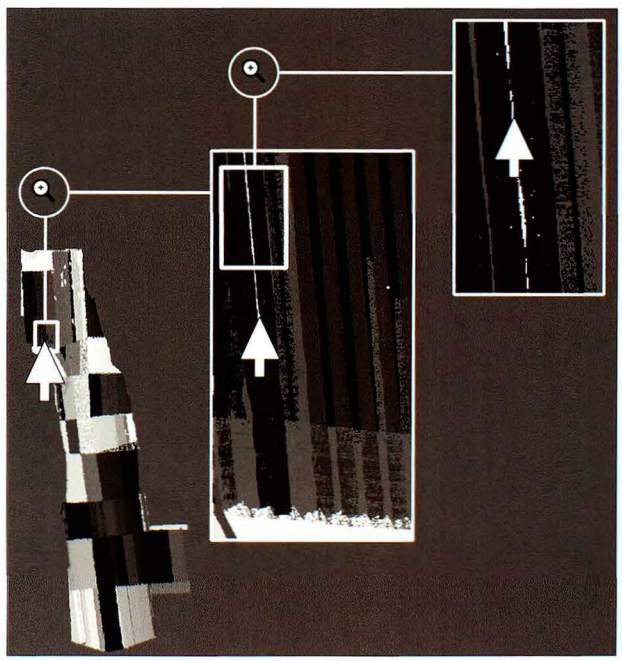

Figure 2: To the left the tracks of the survey of Drogden, centre and right are zoom-ins. The arrow points at a track (in white) displaced vertically with respect to its neighbours

common estimate of the distance together with an estimated variance. Notice that this estimate of the distance also can be found as the difference of averages of the depths in each DTM separately, i.e. it is relatively robust with respect to position errors in the depths. By way of explaining this point, suppose that one of the tracks is shifted less than the width of a cell in some direction. Then the effect on the average depth is in general determined by the change at the boundary and it follows, that the maximum effect on the distance between the two tracks can be estimated from the cells at the boundary of $V_i \cap V_i$. Estimates of this kind were not taken into account when the weights of the observations in the leveling network were determined. Instead it was accepted that position errors might result in gross errors in some of the distance estimates and it was left to the down-weighting algorithm in the adjustment to sort things out.

Now, employing the above method one set of observations of differences in level between nodes in the network was calculated. A second set of observations is found by noticing the fact that the tracks are measured by RTK. In terms of the leveling network this means, that the height of each node has been measured with an accuracy, which may be taken from the data sheet of the instrument. By construction, when the survey is connected all the nodes have to be assigned the same depth, which for convenience was set to zero.

Notice, that it results from the integral above, that the estimated depth difference between two different surveys of the same track will be robust with respect to changes in the s/v if the full angular sector ±60° is used. The same holds true for cross lines perpendicular to the track. In general, however, changes in the s/v during the survey will cause the difference estimates to be off, thus adding to the noise.

The adjustment was computed with software borrowed from Kort & Matrikelstyrelsen. The program was originally developed at the Danish Geodetic Institute and was from the outset in the mid-sixties endowed with an algorithm, which multiplies the weight of any observation by a monotonous function of the size of the corresponding residual (Eeg, 1986). In this way gross errors are isolated as the adjustment is iterated until the nodes stop changing position. For the case at hand, this algorithm helped to isolate the influence of sea weed on the adjustment.

Analysis of the Displacements

The least squares estimates of the displacements of the tracks were split up into two separate sets, according to whether they were measured by vessel 01 or 02. Figure 3 depicts the distribution of the vertical displacements of the tracks against the time of survey for the 0-boats. The circled areas in the figure contain offsets of tracks with a relatively large quantity of seaweed. It was established, that for these tracks the above mentioned pooled distance measurements had large estimated variances. No check was kept on position errors on slopes, because in general the surveyed area was level or gently sloping, with steep slopes only near the channel and the visual inspection of the DTM did not reveal any characteristic pattern in those areas like for example that of slats in a Venetian blind.

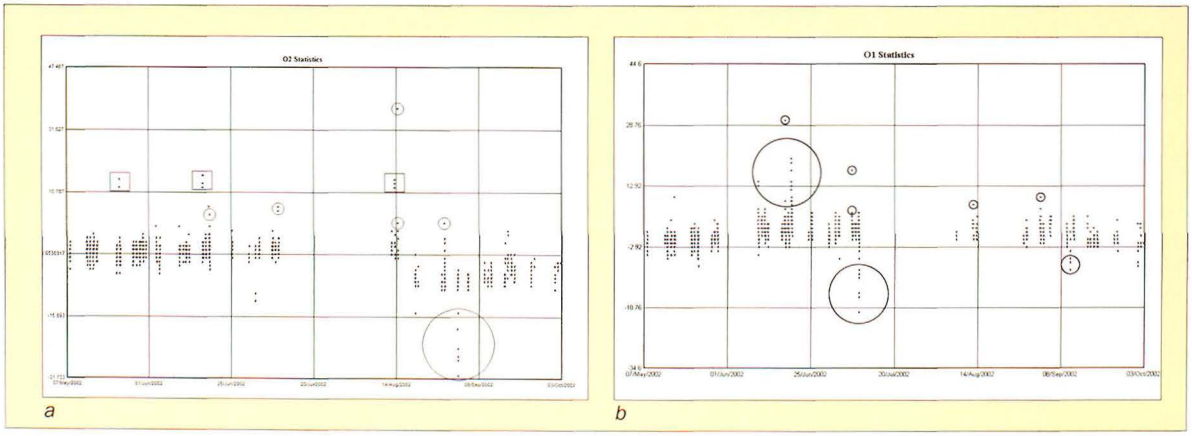

Figure 3: Adjusted corrections (in cm) to the tracks measured by 02 and 01

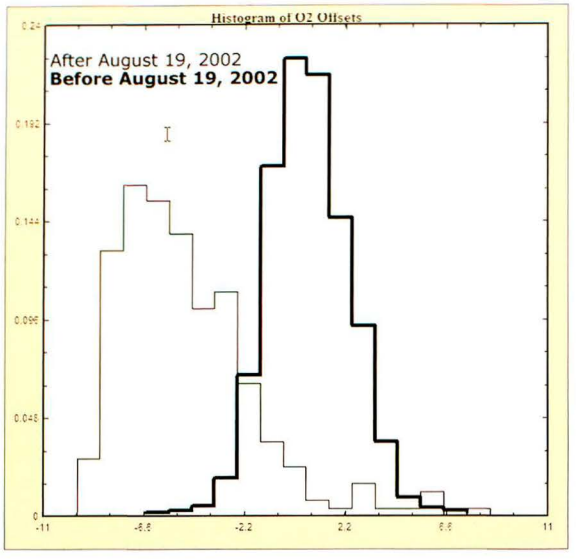

Figure 4: Histogram of O2 offsets

The boxed-in areas in Figure 3 contain displacements related to cycle slips in the RTK. The size of these blunders is reflected in a significant change in the pseudo water level, which normally would have been detected during the survey. The blunder, viz. Table 1 and the 3 elevated tracks in Figure 2, was caused by an error in the fixed solution of the ambiguity at the start of survey 14 August. The remaining blunders appeared and disappeared in the time span between the end of one track and the start of the next. This incident has caused the procedure at start of a day's survey to include a check up of the pseudo water level against the actual water level. Furthermore it has been suggested to EIVA to include the average pseudo water level from the preceding track in the display.

From Figure 3 it is obvious that the level of the adjusted corrections for vessel 02 is changed at some time after 15 August, even though, in the Figure, all the corrections have been rounded to the nearest centimetre thus masking the distribution. Figure 4 depicts 2 histograms of the adjusted corrections, one covering the offsets of the tracks surveyed before 19 August, the other the remaining part of the survey.

An estimate of the change of level between the two periods based on the peaks of the two distributions yields 7cm. Now, it so happens that the Danish Vertical Reference was changed in 2002 from DNN to DVR90. In order not to create any confusion it was decided that Drogden channel should be surveyed throughout in DNN, after which the correction from DNN to DVR90 was applied. In the area covered by the survey this correction varies between 6.6cm and 6.8cm. During an upgrade of the survey software on 19 August, a configuration file was apparently overwritten, causing the default geoid to be selected - and at that time of the year the default geoid was based on DVR90! Figure 5 depicts the estimated deviations corrected to DNN.

It appears from Figure 3 that there is a seasonal variation in the estimated displacements of the areas surveyed by 01, starting low in the spring, attaining a maximum in the summer and then dipping slightly at the end of the season. This behavior is not confirmed from Figure 5, thus making it vessel 01 specific. On average, areas surveyed by 01 before 30 May is situated 3 cm below areas surveyed between that date and 19 August. Now, the 0-boats are equipped with an open caisson for the 8101, which is fitted with an automatic system which regulates the elevation and lowering of the echo sounder, manufactured in such a way, that a light is turned on if and only if the echo sounder is fully submerged. On the other hand, there is no safe guard which prevents surveying if, for some reason the echo sounder is not fully submerged. The system is error prone, however, and

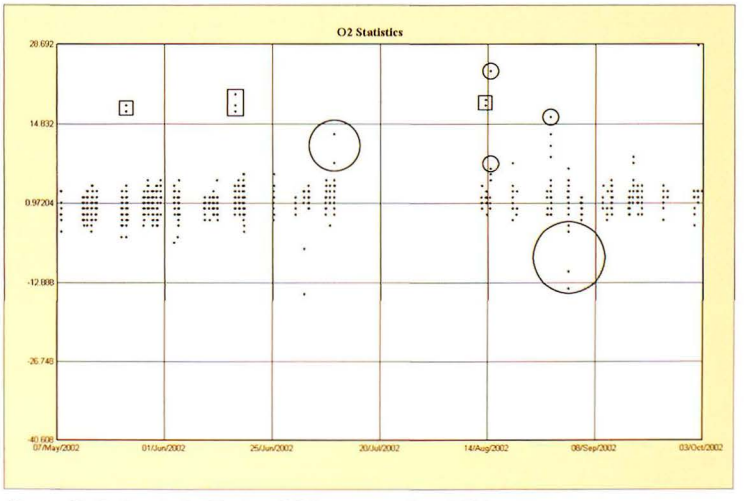

Figure 5: Estimated offsets of 02 corrected to DNN

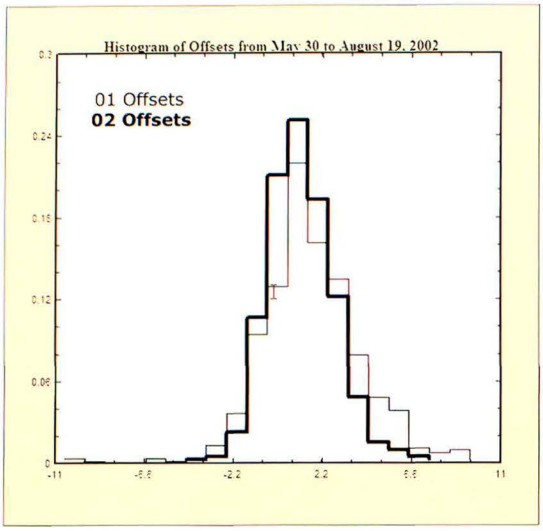

Figure 6 depicts histograms of the offsets of 01 and 02 in the period between 30 May and 19 August 2002

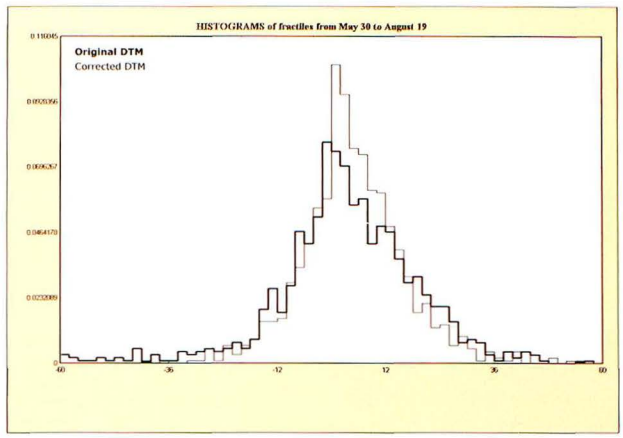

Figure 7: Histograms of fractiles from 30 May to 19 August

reported malfunctioning several times during the season, starting in April. To complete the picture, one of the outboard engines was repaired between 30 May and 4 June, during which period 01 was taken ashore. Of course, it is mere speculation that something happened to the system during this period, i.e. that the echo sounder did measure in the month of May even though it was not fully submerged – a mere 1.5cm would suffice to explain the error.

The reason for ruling out the period before May 30 is that the estimates of the tracks measured by 01 had an offset of 3cm during this period. I've not been able to verify the reason for this behavior, so I've chosen to exclude the data from this period, when the two O-boats are compared. Table 3 depicts the averages and standard deviations of the estimates for said period.

The fact that the averages are positive in Table 3 is due to the exclusion of the first and last months of the survey. The positions of the sensors in the O-boats relative to the co-ordinate system of the ship have been determined by a least squares adjustment. The estimated vertical difference between the GPS antennae and the transducer is 0.5cm, so the difference between the averages of the two O-boats is well within the expected limits. Furthermore, the standard deviations are almost equal, but altogether too large considering the fact that the estimates are biases. Of course, one would expect the noise from the observed distances to be projected by the least squares adjustment into the space of corrections to the Z-component of the tracks. For example, if the observed distances in the least squares adjustment are replaced by random drawings from a normal distribution N(0,3cm), i.e. white noise, then the resulting histogram looks very much like the one in Figure 6 - shifted to zero, no outliers and with an estimated standard deviation of 1.6cm. Given that there is no check on the estimated variance of the observations, because a small shift in horizontal position may have a large influence on the estimate depending on the topography of the sea bed, statistical arguments to separate signal from noise in the above distribution are difficult, if at all possible, to carry through. On top of that the seaweed introduces noise which is dispersed by the least squares adjustment, and the spatial change of the s/v in the water column contributes to the picture too, so it is obvious that a part, if not all, of the distribution in Figure 6 can be explained away as noise.

	Average	Standard deviation	Number of estimates
0-1	1.6cm	1.7cm	495
0-2	1.3cm	1.5cm	389

Table 3: Means and standard deviations of offsets for the O-boats in the period 30 May to 19 August 2002

In order to decide whether there is a signal present in Figure 6, we turn to the above mentioned quotient $u_i = \frac{2n_i - m_i}{\sqrt{m_i}}$. Figure 7 depicts the distribution of u_i for the original DTM of Drogden channel and for a

DTM based on the tracks after they have been corrected by the offsets determined by the least squares adjustment.

In general, a reduction of the distance which separates two tracks results in a smaller value of u_i. Judging by the relatively small change in the bodies of the distributions in Figure 7, the distributions of the adjusted offsets in Figure 6 mainly consist of noise introduced by errors in the 'observed' difference in level between tracks. The change in standard deviation from 33 to 25 passing from the original DTM to the corrected one is probably due to the disappearance of a substantial part of the tail.

Now, the fact that a track moves from the tail to the centre of the distribution in Figure 7 does not imply the presence of a gross error in its Z-component.

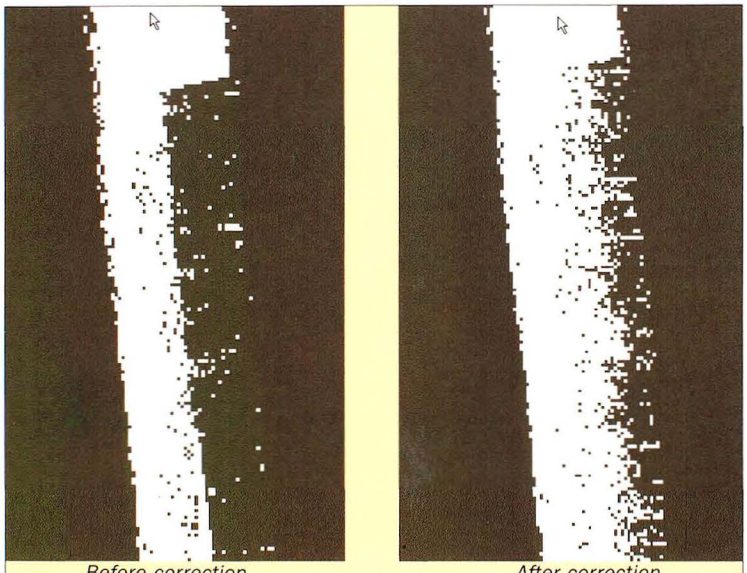

Figure 8: Track placed 15cm below sea bed

Offsets in its neighbours may cause the same response, as seen from Figure 2, where the offset of the track at the end of the arrow is 2cm, while the two tracks covering it are offset by 18cm and 19cm respectively. Alternatively, on a slope a position error may have the same effect. However, it is possible to locate tracks with large offsets in the tail of the distribution. Figure 8 depicts the image of a track offset by -15cm, its right side covered by another track, in the original and in the corrected DTM. For this track the pseudo water level only changed 4cm. A systematic search through tracks with quotients $|u_i| > 40$ revealed 5 tracks with offsets between 5 and 7cm, but blunders at this scale cannot be investigated properly considering the noise in the population.

Conclusion

A new tool has found its way into the surveyor's toolbox. It offers the surveyor a systematic way to check up the post-processed survey for blunders in the vertical component, allowing him to concentrate his efforts on those parts of the survey where the probability of detecting a blunder is the highest. Moreover, by drawing on the analogy between multibeam surveys and leveling networks, a new way to introduce statistical tests into post-processing is opened.

Above, some examples of how to use the leveling network to compare the performance of different vessels and to check the observations for systematic errors have been given. The examples have been chosen in order to demonstrate the precision of the method, rather than the errors themselves which in this context are of minor interest and, once found, result in changed survey procedures.

In order to exploit the tool to its fullest, it is very important to keep record of any changes in the daily routine during the survey, to plan the survey so that neighboring tracks are surveyed at different epochs and to allow for a generous amount of cross lines. For the case in point, too few cross lines were planned but this deficiency was partly made up by the need to close gaps. Furthermore, when several vessels participate in the survey, tracks measured by different vessels should be mixed too, for example when the cross lines are measured – every second one at the start and the other half at the end of the survey – and when the gaps in the survey are filled. This procedure is nothing but good hydrographic survey practice anyway.

One of the objectives of this investigation was to identify and possibly rectify instances of cycle slips

which on account of their size could not be detected by the pseudo water level control. This objective was not met, probably because of the noise introduced by sea weed and s/v errors.

Acknowledgements

The author is thankful for the support from the surveyors at RDANH and especially for the help and advice offered by Morten Sølvsten, guiding him through the ins and outs of practical hydrographic surveying at RDANH, whether adhering to the procedures or stepping outside.

[1] Hare, Rob, (1995). Depth and Position Error Budgets for Multibeam Echosounding. *International Hydrographic Review, 1995*, vol LXXII(2)

[2] Eeg, Jørgen, (1999). Towards Adequate Multibeam Echosounders for Hydrography. *International Hydrographic Review, 1999*, vol LXXVI(1)

[3] Eeg, Jørgen, (1986). On the Adjustment of Observations in the Presense of Blunders. *Geodætisk Institut Technical Report no. 1*, 1986

Biography

Jørgen Eeg is head of the section of validation of hydrographic data at the Royal Danish Administration of Navigation and Hydrography. He graduated as a geodesist from the University of Copenhagen in 1972 and worked with approximation of the potential field of the earth by collocation, integrated geodesy and continuous modelling of plane networks until 1987. At that time the emerging graphic capabilities of workstations and the need to automate work with large data sets led him, following a brief spell of digital picture processing and digital cartography, into the field of hydrography, where he has worked since 1990.

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