Rank-Defect Adjustment Model for Survey-Line Systematic Errors in Marine Survey Net

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1 Introduction

The survey-line mode is usually used in marine survey, such as bathymetry, gravimetry and magnetic survey, in which the survey-lines, including main lines and reference lines, consist of a net and main lines intercross with reference lines. The differences of observations at the crossing points between main lines and reference lines are usually the only information to check the accuracy of the observations\[1,3\]. It is rarely researched that if those differences of observations could be used to raise the precision of survey data. In fact, the semi-systemic error correction model (SSECM)\[4\] based on statistics used in marine gravimetry in China is not perfect in data processing. In other words, the theoretical model of error adjustment for marine survey-line data has not been established yet.

The rank-defect characteristic of the adjustment of marine survey-line data is first discovered in this paper. On the basis of survey-line systematic error structure, marine survey net’s rank-defect model (MSNRDM) is deduced and proved as a normal form of rank-defect adjustment model for marine survey-line data processing.

2 The error model and its rank-defect characteristic

The data collection is often executed in a way of survey line in marine survey. The velocity of the carrier (usually as survey boat) is relatively stable in short time on a survey line and the general effects of tide and wave on observed data vary low. In
In a word, the observation conditions along a survey line can be regarded as invariable and the effects on the survey data nonvariant. Therefore, the systematic effect along a survey line can be regarded as a relatively stable constant (called the survey line systematic error).

2.1 The basic error model

There are usually \(m\) main lines and \(n\) reference lines in a survey area at sea and there are \(m \times n\) (marked as \(mn\)) crossing points when each main line intercrosses with each reference line. Thus at the crossing points, the observed values (shown as matrix \(D\)) on main lines, the observed values on reference lines (shown as matrix \(\tilde{D}\)) and their differences (shown as matrix \(\Delta\)) can be expressed as follows:

\[
D = \begin{bmatrix}
D_{11} & \cdots & D_{1n} \\
\vdots & & \vdots \\
D_{m1} & \cdots & D_{mn}
\end{bmatrix}
\tilde{D} = \begin{bmatrix}
\tilde{D}_{11} & \cdots & \tilde{D}_{1n} \\
\vdots & & \vdots \\
\tilde{D}_{m1} & \cdots & \tilde{D}_{mn}
\end{bmatrix}
\]

\[
\Delta = D - \tilde{D} = \begin{bmatrix}
\Delta_{11} & \cdots & \Delta_{1n} \\
\vdots & & \vdots \\
\Delta_{m1} & \cdots & \Delta_{mn}
\end{bmatrix}
\]

where \(D_{ij}\), \(\tilde{D}_{ij}\) are, respectively, the observed values at the crossing point of the \(i\)th main line and \(j\)th reference line, and \(\Delta_{ij} = D_{ij} - \tilde{D}_{ij}\).

Were there no errors in observed data, \(D_{ij}\) would be equal to \(\tilde{D}_{ij}\) and \(\Delta = 0\). But in fact, \(\Delta \neq 0\), so the error model is given below:

\[
\begin{align*}
D_{ij} &= d_{ij} + a_0 + a_i + \delta_{ij} \quad \text{(main line)} \\
\tilde{D}_{ij} &= d_{ij} + b_0 + b_j + \tilde{\delta}_{ij} \quad \text{(reference line)}
\end{align*}
\]

where \(i = 1, 2, \ldots, m; j = 1, 2, \ldots, n; d_{ij}\) is the true value at the crossing point of the \(i\)th main line and the \(j\)th reference line; \(a_0\) is the systematic effect on all of main lines, \(b_0\) is that on all of reference lines, \(a_i\) is that only on the \(i\)th main line and \(b_j\) is that only on the \(j\)th reference line. They are comprehensive effects of all environmental factors on observed data, \(\delta_{ij}, \tilde{\delta}_{ij}\), are random errors at the crossing point, which are regarded as a normal distribution \(N(0, \sigma^2)\). Therefore, the difference \(\Delta_{ij}\) at the crossing point is shown as

\[
\Delta_{ij} = D_{ij} - \tilde{D}_{ij} = (a_0 - b_0) + (a_i - b_j) + (\delta_{ij} - \tilde{\delta}_{ij})
\]

(3)

Let \(\xi_{ij} = \delta_{ij} - \tilde{\delta}_{ij}, c_0 = a_0 - b_0\), where \(c_0\) is called area systematic error. Eq. (3) shows that \(\Delta_{ij} = c_0 + a_i - b_j + \xi_{ij}\), so it can be shown with matrix expression as follows:

\[
\Delta = C_0 + A - B + \xi
\]

(4)

where

\[
\begin{align*}
C_0 &= \begin{bmatrix} c_0 & \cdots & c_0 \\ \vdots & & \vdots \\ c_0 & \cdots & c_0 \end{bmatrix} \\
A &= \begin{bmatrix} a_1 & \cdots & a_1 \\ \vdots & & \vdots \\ a_m & \cdots & a_m \end{bmatrix} \\
B &= \begin{bmatrix} b_1 & \cdots & b_n \\ \vdots & & \vdots \\ b_1 & \cdots & b_n \end{bmatrix}
\end{align*}
\]

and

\[
\begin{align*}
\xi &= \delta - \tilde{\delta} = \begin{bmatrix} \xi_{11} & \cdots & \xi_{1n} \\ \vdots & & \vdots \\ \xi_{m1} & \cdots & \xi_{mn} \end{bmatrix} \\
\delta &= \begin{bmatrix} \delta_{11} & \cdots & \delta_{1n} \\ \vdots & & \vdots \\ \delta_{m1} & \cdots & \delta_{mn} \end{bmatrix} \\
\tilde{\delta} &= \begin{bmatrix} \tilde{\delta}_{11} & \cdots & \tilde{\delta}_{1n} \\ \vdots & & \vdots \\ \tilde{\delta}_{m1} & \cdots & \tilde{\delta}_{mn} \end{bmatrix}
\end{align*}
\]

There are \(m + n + 2\) parameters in Eq. (3) and \(m + n + 1\) parameters in Eq. (4). The effects of systematic errors on the observed data will be removed if parameters \(a_0, b_0\) (or \(c_0\)), \(a_i\) and \(b_j\) are determined.

2.2 Characteristic of model’s rank-defect

The differences at crossing points are usually the only data available to check the observation quality in marine survey. From the normal theory of error adjustment, it is well known that it is impossible to estimate two parameters from one observation value. In fact, it is short of initial data to determine two or three sorts of unknown parameters \((a_i\) and \(b_j\) or \(a_0\) and \(b_0\)) in Eq. (3) or Eq. (4) if the differences at crossing points have only been used. We can compare marine survey net with the level-
ing control net. If there are only height differences in leveling net, one or more known points’ heights must be provided to compute the heights of the other unknown points. In this case, the characteristic of Eq. (3) or Eq. (4) that lacks of initial data is called their rank-defect characteristic.

3 The rank-defect adjustment model and its error correction method

3.1 Deduction of rank-defect model

Let \( L_{ij} \) be replaced by \( \Delta_{ij} \) and \( v_{ij} \) by \( -\xi_{ij} \), then Eq. (4) can be expressed as follows:

\[
V_{m,n} = C_{m,n} + A_{m,n} - B_{m,n} - L_{m,n} \tag{5}
\]

where

\[
V = \begin{bmatrix}
  v_{11} & \cdots & v_{1n} \\
  \vdots & \ddots & \vdots \\
  v_{mn} & \cdots & v_{nn}
\end{bmatrix}
\]

Eq. (5) can be further changed as below:

\[
V_{mn\times 1} = C_{mn\times (m+n+1)}X_{(m+n+1)\times 1} - L_{mn\times 1} \tag{6}
\]

where

\[
N = C^T C = \\
\begin{bmatrix}
  mn & -e_m^T & -e_n^T \\
  -e_m & nE_m & -e_n e_m^T \\
  -e_n & e_n e_m & mE_n
\end{bmatrix}_{(m+n+1)\times (m+n+1)}
\]

It can be proved that the rank of matrix \( N \) or \( C \) is \( m + n - 1 \) (the proof is omitted) and its rank-defect number is 2.

There are many solutions to Eq. (7) from the theory of rank-defect adjustment\([5,6]\). Therefore, the following constraint condition is used here:

\[
G^T \hat{X} = 0 \tag{8}
\]

where the rank of \( G \) is 2.

Eq. (8) is an adjustment datum, which is equivalent to \( \hat{X}^T \hat{X} = \min \). On the basis of classification of systematic errors in Eq. (2), the following four sorts of the adjustment datum may be used:

1) \( G_1^T = \begin{bmatrix} 1 & -e_m^T & 0_{1\times n} \\ 0 & e_m^T & e_n^T \end{bmatrix} \)

\[
e_0 = \sum_{i=1}^{m} a_i, \sum_{j=1}^{n} b_j = 0
\]

and is equivalent to \( \hat{X}^T \hat{X} = \hat{X}^T \hat{X}_c + \hat{X}^T \hat{X}_a + \hat{X}^T \hat{X}_b = \min \).

2) \( G_2^T = \begin{bmatrix} 1 & -e_m^T & 0_{1\times n} \\ 0 & e_m^T & e_n^T \end{bmatrix} \)

\[
e_0 = 0, \sum_{i=1}^{m} a_i = 0
\]

and is equivalent to \( \hat{X}^T \hat{X}_c + \hat{X}^T \hat{X}_b = \min \).

3) \( G_3^T = \begin{bmatrix} 1 & -e_m^T & 0_{1\times n} \\ 0 & e_m^T & e_n^T \end{bmatrix} \)

\[
e_0 = 0, \sum_{j=1}^{n} b_j = 0
\]

and is equivalent to \( \hat{X}^T \hat{X}_c + \hat{X}^T \hat{X}_a = \min \).

4) \( G_4^T = \begin{bmatrix} 1 & 0_{1\times m} & 0_{1\times n} \\ 0 & 0_{1\times m} & 0_{1\times n} \end{bmatrix} \)

\[
e_0 = 0, \sum_{i=1}^{m} a_i = 0
\]

and is equivalent to \( \hat{X}^T \hat{X}_c + \hat{X}^T \hat{X}_b = \min \).

Using Eq. (8), the following adjustment model can be obtained:

\[
V = \hat{C}X - L, P_L = E_{mn}
\]

\[
G^T \hat{X} = 0 \tag{13}
\]

\[
V^T V = \min
\]

Eq. (13) can be further developed to improve its availability as follows\([5]\):
\[ V = C\hat{X} - L, \Sigma_L = P_L^{-1} \sigma_0^2 \]
\[ G^T P_X \hat{X} = 0 \]
\[ V^T P_L V = \text{min} \]
\[ \hat{X} = (N + P_X G G^T P_X)^{-1} C^T P_L L \]
\[ Q_X = (N + P_X G G^T P_X)^{-1} N (N + P_X G G^T P_X)^{-1} \]
\[ \sigma_t^2 = V^T P_L V / [(m - 1) \times (n - 1)] \tag{14} \]

where \( V \) is the residual vector; \( C \) is the designed matrix; \( \hat{X} \) is the parameter vector; \( P_L \) is the weight matrix of observation; \( G \) is the constraint matrix; \( P_X \) is the parameter weight matrix; \( Q_X \) is the parameter coefficient weight matrix and \( \sigma_t \) is the mean square error of unit weight.

Eq. (14) is called marine survey net’s rank-defect model (MSNRM). Since \( P_L \) and \( P_X \) in Eq. (14) are considered, Eq. (14) can be regarded as a normal adjustment model for data processing in the marine survey net.

The parameter values from Eq. (14) should be further tested to determine whether those parameters are significant or not. If a parameter is significant, it will be used to correct the data in Eq. (2).

There may be many test methods from statistics theory, but only T-test and linear supposition test methods are used in this paper, for the prior unit weight mean error \( \sigma_0 \) in Eq. (14) is unknown.

1) T-test

In accordance with T-test method, the statistic variable is established as follows:
\[ t = \frac{\hat{x} - 0}{\sigma_x} = \frac{\hat{x}}{\sigma_t \sqrt{q_x}}, \quad |t| \leq t_{a/2} \tag{15} \]
where \( \hat{x} \) is the value of parameter, \( \sigma_x \) is the variance of \( \hat{x} \), and \( a \) is the significance level.

2) Linear supposition test

From the linear supposition test method\(^6\), the following model is used:
\[ \begin{align*}
V &= C\hat{X} - L \\
G^T P_X \hat{X} &= 0 \\
H\hat{X} &= 0
\end{align*} \tag{16} \]

where \( H \) is a matrix whose design depends on parameter values to be tested. Let \( Q_1 = V_1^T P_L V_1 \), where \( V_1 \) is from Eq. (16), \( R = Q_1 - Q \), where \( Q = V^T P_L V \), in which \( V \) is from Eq. (14), the statistic variable is established as follows:
\[ F = \frac{R/r(H)}{Q/(m + n - 1)} \leq F_{1-a, r(H), m+n-1} \tag{17} \]

where \( r(H) \) is the rank of matrix \( H \).

3.2 The error correction method

After such parameters as \( c_0 \), \( a_i \), \( b_j \) are determined by Eq. (14), the observed values in Eq. (2) can be corrected so as to remove the effects of errors. The steps to correct errors are given as follows:

1) It is necessary to test whether \( c_0 \) is significant or not. If \( c_0 \) is significant, the area systematic error should be corrected. Because \( c_0 = a_0 - b_0 \), \( a_0 \) or \( b_0 \) can not be determined only from \( c_0 \). Here let \( a_0 = c_0/2, b_0 = -c_0/2 \), and then all the observed data on the survey lines can be corrected as:
\[ \begin{align*}
D_1 &= D - c_0/2 \quad \text{(main line)} \\
\tilde{D}_1 &= D + c_0/2 \quad \text{(reference line)}
\end{align*} \]

where \( D \) is all the observed data on main lines and \( \tilde{D} \) on reference lines.

2) It is necessary to test whether \( a_i \) (or \( b_j \)) is significant or not. If it is, all of the observed data on the survey line can be corrected as follows:
\[ \begin{align*}
D_2 &= D_1 - A \quad \text{(main line)} \\
\tilde{D}_2 &= \tilde{D}_1 + B \quad \text{(reference line)}
\end{align*} \]

where \( D_1, \tilde{D}_1 \) are the corrected data after the first step; if it is not, \( a_i \) (or \( b_j \)) will be considered as random errors and only the data at the crossing points will be corrected.

3) After the above steps, the corrected data includes only the random errors. In view of Eq. (3) and Eq. (4), \( \xi_{ij} = -\nu_{ij} = \delta_{ij} - \tilde{\delta}_{ij} \), it is impossible to determine the \( \delta_{ij} \) and \( \tilde{\delta}_{ij} \) only from \( \xi_{ij} \). Let \( \delta_{ij} = \xi_{ij}/2, \tilde{\delta}_{ij} = -\xi_{ij}/2 \), the data at the crossing points can be further corrected as:
\[ \begin{align*}
D_3 &= D_2 - \delta \\
\tilde{D}_3 &= \tilde{D}_2 - \tilde{\delta}
\end{align*} \]

where \( D_2 \) and \( \tilde{D}_2 \) are just the data at the crossing points after Step 2). The correction is completed.

4 SSECM is a special case of MSNRDM

At present, SSECM used in data processing of the
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marine gravimetry is based on Eq. (4) and obtained from a statistic method[4]. The SSECM can be proved as a special case of Eq. (14) here.

Let \( S = \frac{e^{T} \Delta_{m}}{mn} \), \( S_{i,j} = \frac{e^{T}_{m} \Delta_{i}}{n} \), \( i = 1, \ldots, m \);

\( S_{j} = \frac{e^{T}_{m} \Delta_{m}}{m} \), \( j = 1, \ldots, n \), where \( i \) stands for the \( i \)th row vector and \( j \) for the \( j \)th column vector of \( \Delta \) in Eq. (1), \( L^{T} = (L_{11}^{T}, L_{12}^{T}, \ldots, L_{mm}^{T})_{1 \times m}, L_{j}^{T} = (L_{i1}, L_{i2}, \ldots, L_{in})_{1 \times n} \), and \( P_{L} \) in Eq. (14) is an identity matrix, then the normal Eq. (7) becomes the following:

\[
\begin{bmatrix}
mn & ne^{T}_{m} - me^{T}_{n} \\
nm & ne^{T}_{m} - me^{T}_{n} - e_{n}e^{T}_{m} \\
- me^{T}_{n} & me^{T}_{n} - e_{n}e^{T}_{m} & mE_{n}
\end{bmatrix}
\begin{bmatrix}
\hat{X}_{T} \\
\hat{X}_{b}
\end{bmatrix}
= 
\begin{bmatrix}
(e_{n}^{T}(L_{11} + L_{22} + \cdots + L_{mm})) \\
- (e_{n}^{T}(L_{11} + L_{22} + \cdots + L_{mm}))
\end{bmatrix}
\]

The results in Eq. (19) are the same as those in Reference [4] because \( G^{T} = \begin{bmatrix} 0 & -e_{m}^{T} & 0_{1 \times n} \\
0 & e_{m}^{T} & e_{n}^{T} \end{bmatrix} \) and it shows that \( \sum_{i=1}^{m} a_{i} = 0, \sum_{j=1}^{n} b_{j} = 0 \), i.e., \( \frac{1}{m} \sum_{i=1}^{m} a_{i} = 0, \frac{1}{n} \sum_{j=1}^{n} b_{j} = 0 \), which is equivalent to the assumption that \( mn_{0}, na_{i} \) and \( b_{j} \) are larger than the other items in SSECM[4].

The above proves that the SSECM in Reference [4] is a special case of MSNRFDM in this paper.

5 Example and analysis

Assuming that there are 12 \( (m) \) main lines and 12 \( (n) \) reference lines in a marine gravimetry area. The difference data[1,4,7] at their crossing points is shown in Table 1.

The data in Table 1 are regarded as with the same precision and \( P_{L}, P_{x} \) in Eq. (14) as identity matrices. According to Eq. (14), \( \hat{X} \) are computed and listed in Table 2 and Table 3 when \( G^{T} \) is equal to \( G_{1}^{T}, G_{2}^{T}, G_{3}^{T} \), moreover, \( \sigma = \sqrt{V^{T}P_{L}V/(m-1)(n-1)} = 0.95 \times 10^{-5} m\cdot s^{-2} \), i.e. \( \delta_{2/2} = \sqrt{V^{T}P_{L}V/[2(m-1)(n-1)]} = 0.67 \times 10^{-5} m\cdot s^{-2} \).

The results in Table 2 show the differences among \( G_{1}^{T}, G_{2}^{T}, G_{3}^{T} \). In general, we had better use \( G_{3}^{T} \hat{X} = 0 \) as a constraint condition when none of survey line can be surely considered to contain systematic error before adjustment. Actual-
ly, how to select the constraint condition depends on real time survey's environment and errors' characteristics at sea.

The parameter values are tested by $T$-test method (here the significance level $a = 0.05$), and it is found that all the parameters except $c_0, a_6$, $a_{10}$, are significant. The residuals at crossing points after the former two correction steps are listed in Table 4.

In order to compare SSECM with MSNRDM, the parameter results from SSECM are listed in Table 5.

| Table 2 | The line systematic error parameter values under different constraint conditions/10$^{-5}$m$^2$s$^{-2}$ |
|---------|---------------------------------------------------------------|
| Number  | $G_1$            | $G_2$            | $G_3$            | $G_4$            |
|         | $a$     | $b$     | $a$     | $b$     | $a$     | $b$     | $a$     | $b$     | $a$     | $b$     | $a$     | $b$     |
| 1       | -5.95   | 1.30    | -5.94   | 1.29    | -5.94   | 1.40    | -6.05   | 1.29    | 1.29    |
| 2       | -0.93   | 8.78    | -0.92   | 8.78    | -0.92   | 8.88    | -1.03   | 8.78    | -1.03   |
| 3       | -7.87   | 1.90    | -7.86   | 1.90    | -7.86   | 2.01    | -7.98   | 1.90    | -7.98   |
| 4       | -2.24   | 2.17    | -2.23   | 2.16    | -2.23   | 2.28    | -2.34   | 2.16    | -2.34   |
| 5       | 1.97    | -6.07   | 1.98    | -6.08   | 1.98    | -5.97   | 1.87    | -6.08   | -6.08   |
| 6       | 0.27    | 5.26    | 0.27    | 5.26    | 0.27    | 5.37    | 0.16    | 5.26    | 5.26    |
| 7       | -6.77   | -3.47   | -6.76   | -3.47   | -6.76   | -3.36   | -6.88   | -3.47   |
| 8       | 3.11    | -1.85   | 3.12    | -1.86   | 3.12    | -1.75   | 3.01    | -1.86   |
| 9       | 6.13    | -3.83   | 6.14    | 0.07    | -3.84   | 6.14    | -3.72   | 6.02    |
| 10      | 0.06    | 2.57    | 0.07    | 2.56    | 0.07    | 2.67    | -0.94   | 2.56    |
| 11      | 7.21    | -5.88   | 7.22    | -5.88   | 7.22    | -5.77   | 7.11    | -5.88   |
| 12      | 4.93    | -0.81   | 4.93    | -0.82   | 4.94    | -0.71   | 4.82    | -0.82   |

| Table 3 | The area systematic error parameter values under different constraint conditions/10$^{-5}$m$^2$s$^{-2}$ |
|---------|---------------------------------------------------------------|
| Constraint matrix $G$ | $G_1$ | $G_2$ | $G_3$ | $G_4$ |
|         | $c_0$ | -0.09 | -0.11 | 0     | 0     |

| Table 4 | The residual values at the crossing points after correction/10$^{-5}$m$^2$s$^{-2}$ |
|---------|---------------------------------------------------------------|
| Reference line | 1 2 3 4 5 6 7 8 9 10 11 12 |
| Main line    | 1 2 3 4 5 6 7 8 9 10 11 12 |
| 1           | 0.14 0.12 0.05 0.51 0.47 -1.29 0.38 -0.01 1.51 0.26 -1.84 0.23 |
| 2           | -0.68 0.90 0.03 0.19 1.35 -1.41 -0.04 -0.73 1.39 1.49 0.04 -2.59 |
| 3           | -1.03 -1.45 0.68 0.64 -0.10 1.44 -0.59 0.42 -0.86 -0.36 0.69 0.56 |
| 4           | -0.37 1.11 -1.06 -1.40 0.36 1.10 -1.83 0.88 0.40 0.20 0.25 0.32 |
| 5           | 1.72 -0.70 0.03 0.79 0.15 0.19 0.46 -0.63 -1.71 -0.01 0.04 -0.39 |
| 6           | 1.53 -0.99 0.34 -0.30 0.06 -0.60 -0.63 0.18 -0.20 -0.50 -0.15 1.22 |
| 7           | -0.43 0.75 -0.32 1.14 0.00 0.44 -0.89 0.72 -1.56 -1.06 1.39 -0.14 |
| 8           | 0.18 0.86 -0.11 -1.45 -2.59 -0.65 1.42 0.33 1.55 -0.35 0.20 0.57 |
| 9           | 1.67 0.45 0.08 -0.06 0.20 -1.36 0.99 0.22 -0.56 0.64 -0.51 0.26 |
| 10          | -1.87 -0.49 0.24 -0.20 1.16 0.90 0.37 0.08 0.20 0.10 -0.85 0.32 |
| 11          | -1.42 0.16 -0.41 -0.25 0.11 0.35 1.62 0.13 -0.35 0.56 0.10 -0.63 |
| 12          | 0.57 -0.75 0.48 0.34 -1.20 0.94 0.71 -1.58 0.14 -0.46 0.59 0.26 |

| Table 5 | The systematic error parameter values from SSECM/10$^{-5}$m$^2$s$^{-2}$ |
|---------|---------------------------------------------------------------|
| Survey-line | 1 2 3 4 5 6 7 8 9 10 11 12 |
| Parameter  | $a$ | $b$ | $c_0$ | $a_6$ |
| 1          | -5.94 -0.92 -7.86 -2.23 1.98 0.27 -6.76 3.12 6.14 0.07 7.22 4.94 |
| 2          | 1.29 8.77 1.90 2.16 -6.08 5.26 -3.47 -1.86 -3.84 2.56 -5.89 -0.82 |

$c_0 = -0.11$, $a_6 = 0.67$.
It can be seen that the results in Table 5 are the same as those in Table 2 when \( G = G_2 \). Moreover, the correction results in Table 4 are the same as those in Reference [4]. Hence, this calculation shows that SSECM is a special case of Eq. (14). Furthermore, there is a wide selectivity about constraint conditions, parameter test and the observation's weight in model Eq. (14) that is available to various marine survey-line data processing.

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Notes to Contributors

Contributions are welcomed on one of the following subjects or in related areas:

- GIS
- Geodynamic
- GPS
- Geo-surveying
- RS
- Photogrammetry
- Cartology
- Graphics
- Physical geo-surveying
- Engineering surveying
- Mapping apparatus

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