Magnetic Compensation of Magnetic Noises Related to Aircraft’s Maneuvers in Airborne Survey

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• Effects of aircraft motion on data
  a) What are the effects?
  b) Traditional approaches
  c) Why Study Compensation? – methodology, direction

• Investigation of some fundamentals
  a) Solvers, Filters
  b) The use of synthetic data

• Compensation with multiple GPS antennae
  a) Methodology
  b) Results

• Where to from here?
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OVERVIEW

**BASICS**
- New generations of optically pumped sensors have their sensitivity quoted in pT
- New instrumentation is also attempting to measure high accuracy vector data.
- Aircraft/helicopter itself emanates magnetic signals
- Compensation a limiting factor in obtaining highly accurate data

**TOPICS**
1) problems and techniques related to removing the effects of the moving platform
2) attempts to study the subject with the use of simulated data.
3) Attempts to use GPS data as orientation
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**BASICS**

- 3-axes fluxgate

Total field sensor

- Permanent
- Induced
- EM?

- Aircraft (helicopters, moving platforms) are magnetic
- Magnetic effects VARY with the aircraft’s attitude – (wrt $B_0$)
- Motion within $B_0$, Gradients in $B_0$, heading effects
- Determine the effects as a function of attitude and rotation rates
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**METHOD**

\[ \mathbf{B}_T = \sum C_i a^i, \ i=1,N \quad \text{Leliak, 1961} \]

- \( C_i, \ i=1,3 \) - permanent
- \( C_i, \ i=4,9 \) - induced
- \( C_i, \ i=10,18 \) - induced EM
- \( C_i, \ i=19,? \) - gradients, heading effects, em noise

\[ a_i = f^i (\cos X, \cos Y, \cos Z) \text{ or } B_0 g^i (\cos X, \cos Y, \cos Z) \]

\[ B_0 h^i [ \frac{d}{dt} (\cos X, \cos Y, \cos Z) ] \]

where \( \cos(\ldots) \) are direction cosines of the aircraft’s axes wrt to \( B_0 \) traditionally from fluxgate data

- find \( c_i \) at altitude in a *uniform field*
  and apply corrections to survey data
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Issues and Objectives

• History clouded
  military, exploration
• Adequacy of assumed mathematical system
  number of terms, synthetic models
• Solution techniques
• Sensor, Gradient effects
  box data
• Effects of non-uniform fields – gradients, anomalies
• GPS attitude
  fluxgate data not actually used to determine orientation
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Issues and Objectives - 1

- Adequacy of assumed mathematical system
  number of terms, synthetic models, filters

Effect of high-pass filter on synthetic remanent and induced

- Raw mag

- Compensated - Gaussian high-pass

- Compensated - no high-pass

Response (nTesla)

Fiducial
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Issues and Objectives - 1

• Adequacy of assumed mathematical system
  number of terms, synthetic models, filters

✓ Even for induced and permanent system not complete

✓ High-pass introduces noise and DC shift

✓ For synthetic data solvers equivalent
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Issues and Objectives - 2

Solution techniques

\[ \mathbf{AC} = \mathbf{Y}, \quad \mathbf{n}\times\mathbf{m}, \quad n=18, \quad m>>18 \]

1. Ridge Regression  
2. Singular Value Decomposition  
3. Conjugate Gradient  
4. Symmetric Inverse

Compensation example - L9100, Box 217

-raw
-13 SVD
-16 SVD

Absolute X (m) vs. Response (nTesla)
• Aircraft attitude and Filtering
  or Filter the Data or Filter the Operator

- for synthetic data results are equivalent
- Gaussian high-pass best we found

Red curve: 5th term before filtration
Blue curve: 5th term after filtration 0.2Hz cutoff
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Issues and Objectives - 3

- Aircraft attitude and Filtering
  - or Filter the Data or Filter the Operator

Real Data
- Highpass of data easier to understand but not always the best
Sensor, Heading and Gradients Effects

- removal of 1st order gradient does not improve results

- for best results each sensor treated differently – coefficients, solver, filters
Sensor, Heading and Gradients Effects

multiple line coefficients vs single line coefficients

Red curve: measured total field (nT)
Blue: line-to-line compensation results
Green: compensation results with all four box lines
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Issues and Objectives - 5

Use of GPS attitude
- to improve compensation over anomalies
- improve coefficient calculation due to regional effects
- compensate fluxgate data
- fluxgate data not actually used to determine orientation

- Field tests were done with 3 Novatel Millenium geodetic grade, dual frequency GPS’s on Terraquest’s Navajo
- GPS’s were sampled at 10 Hz
- base station was 40 to 70 kms away
- base station a Novatel Millenium sampled at 10 Hz
- differential corrections done with WayPoint software

➤ GPS data has what appears to be a long period drift

➤ Utilized on-board as basestation – 3 local difference vectors
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Issues and Objectives -5

Use of GPS attitude

*Note: Operator terms in Leliak’s system are projections of $B_i$ on $|B|$*

Red: simulated $B_z$
Blue: measured $B_z$

Red: measured $B_{total}$
Blue: compensated total field with FW and FS vectors
Green: compensated total field with measured Fluxgate
The blue and green curves DC shifted.
Use of GPS attitude

Red: measured Btotal
Blue: compensated total field with FW and FS vectors
Green: compensated total field with measured Fluxgate
The blue and green curves DC shifted.
Conclusions

- Synthetic models reveal useful information
- Compensation can be improved under most conditions via the judicious use of different solvers and parameters,
- there are other assumptions within Leliak’s formulation which are only approximations as “perfect” synthetic data cannot be totally compensated.
- some assumptions, such as accurate orientation information from fluxgate magnetometers, are not valid under all circumstances,
- other methods of obtaining orientation data such as using multiple GPS’s are possible
- Ridge regression analysis and truncated singular value decomposition are effective techniques to improve the predicative power of the 16-term and 18-term interference models, particularly when multicolinearities exist in the interference models.
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