On Compensating Magnetometer Swing in UAV Magnetic Surveys

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Research Motivation

To reliably integrate two innovative technologies and provide a technical balance between the existing resolution and coverage capabilities of conventional magnetic surveying platforms.

**Platform**
Multi-Rotor Unmanned Aerial Vehicle

**Sensor**
Lightweight, High-Resolution, Optically Pumped Magnetometer
Conventional Magnetic Surveying Platforms

- **Manned Airborne**
  - Regional Survey Areas (>100 km$^2$)
  - High Coverage Rate (>100 km/h)
  - Relatively Low-Resolution Data

- **Terrestrial**
  - Localized Survey Areas (<10 km$^2$)
  - Low Coverage Rate (<5 km/h)
  - Relatively High-Resolution Data

Walter et al. 2020
Conventional Magnetic Surveying Platforms

- **Manned Airborne**
  - Resolution: Low
  - Coverage: High
  - Ground Surface: ~ 100m

- **Terrestrial**
  - Resolution: High
  - Coverage: Low
  - Ground Surface

**C/O: Sander Geophysics Inc.**

Platforms:

- Conventional Magnetic Surveying
UAV-Borne Aeromagnetic Surveying Platforms

- Manned Airborne
  - Ground Surface ~ 100m
  - Low Resolution
  - High Coverage

- UAV-Borne
  - Subsurface Geologic Target ~ 30m
  - High Resolution
  - Low Coverage

Technical Balance Between Resolution and Coverage

Subsurface Geologic Target
UAV-Borne Aeromagnetic Case Study

Published Manuscript: (1) Walter et al. 2020 - Geophysical Prospecting

- Manned Airborne
- UAV-Borne
- Terrestrial

Resolution
- Low
- High

Coverage
- High Ground Surface
- Low

Subsurface Geologic Target
Integration of the Semi-Rigidly Suspended Magnetometer

DJI S900 Multi-Rotor UAV

GEM Systems - GSMP 35U Potassium Vapour Magnetometer

UAV-Borne Aeromagnetic System

DJI S900 Multi-Rotor UAV

Semi-Rigid Magnetometer Mount

Magnetometer

Published Manuscript: (2) Walter et al. 2019 - Geophysical Prospecting

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Critical Integration Consideration: Magnetic Interference Signals

Magnetic Interference Signals

Setback Distance

Magnetometer

DJI S900 Multi-Rotor UAV

Semi-Rigid Magnetometer Mount

Magnetometer
Measured Magnetometer Setback Distances

DJI S900: ~3m  
(2.2 kg payload)

- Lighter & Smaller UAV
- Smaller Brushless Motors
- Smaller Solenoids
- Smaller Permanent Magnets

DJI Wind 4: ~5m  
(2.2 kg payload)

- Heavier & Larger UAV
- Larger Brushless Motors
- Larger Solenoids
- Larger Permanent Magnets
UAV-Borne Aeromagnetic System Specifications

**DJI S900 Multi-Rotor UAV**
- **Magnetometer Offset Distance:** 3m
- **Payload Weight:** 2.2 kg
- **Power Supply:** 16000 mAh
- **Flight Endurance:** ~15 minutes (@16000 mAh & 2.2 kg payload)

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Data Acquisition System

GEM Systems: GSMP-35U
Potassium Vapour UAV Magnetometer (10 Hz)

Ublox: EVK-7P
GPS (10 Hz)

Lightware: SF-11
Laser Altimeter (20 Hz)

Adafruit: GY-80
10-DOF IMU (80 Hz)

Total Payload Weight 2.2 Kg

Raspberry Pi
UAV-Borne Aeromagnetic Survey for Mineral Exploration

Flight Lines of Entire Survey

Selected Flight Lines for Study

Flight Speed: 7 m/s
Overview of Selected Survey Lines And Flight Maneuvers

- Hovering After Takeoff
- Approach Line
- Wide Corner (50m radius)
- Flight Line 1
- Sharp Corner 1 (12.5 m radius)
- Flight Line 2
- Sharp Corner 2 (12.5 m radius)
UAV-Borne Residual Magnetic Field Data

Hovering

Wide Corner

Sharp Corner 1

Sharp Corner 2
UAV-Borne Aeromagnetic Data Quality

Hovering A
Wide Corner B
Sharp Corner 1 C
Sharp Corner 2 D
Frequency Domain UAV-Borne Residual Magnetic Field Data

Swinging Frequency ~0.3 Hz

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Spectrogram of UAV-Borne Residual Magnetic Field Data

Swinging Signal due to Cornering

High-Gradient Swinging Signal

Hovering

Wide Corner

Sharp Corner 1

Sharp Corner 2

Target Signals

Swinging Frequency ~0.3 Hz

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Isolated Magnetic Signal due to Magnetometer Swing
Isolated Magnetic Signal due to Magnetometer Swing

Swinging Signal due to Cornering

High-Gradient Swinging Signal

Hovering

Wide Corner

Sharp Corner 1

Sharp Corner 2

Swinging Frequency

Walter et al. 2020
IMU Roll Data of Magnetometer

Hovering  A
Wide Corner  B
Sharp Corner 1  C
Sharp Corner 2  D
Swinging Frequency ~0.3 Hz

Frequency Domain IMU Roll Data

Time Domain: Magnetometer Roll

Frequency Domain: Magnetometer Roll
Frequency Domain Comparison of IMU Roll Data and Magnetometer RMI Data

- Frequency ~0.3 Hz
- Target Signal
- Swinging Frequency
  - ~0.3 Hz
Spectrogram of Magnetometer Roll

3m

Swinging Signal due to Cornering

Hovering  
Wide Corner  
Sharp Corner 1  
Sharp Corner 2

Swinging Frequency ~0.3 Hz

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Applying a Low-Pass Filter to Remove Swinging Signals in Magnetic Data

Target Signal

Cut-off Frequency

Swinging Frequency
Spectrogram of Filtered Magnetic Field Data

Target Signals

Swinging

Frequency

~0.3 Hz

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Filtered Magnetic Field Data

Residual Magnetic Field Data Vs. Filtered Magnetic Field Data

Hovering
Wide Corner
Sharp Corner 1
Sharp Corner 2
Conclusions

1. Magnetic signal amplitude of ~2 nT due to the swinging of the magnetometer in sharp corners. Represented in the magnetic data at C & D.

2. Magnetic signal amplitude of ~3 nT due to the swinging of the magnetometer through a high-gradient geomagnetic field. Represented in the magnetic data at Flight Line 1 and Flight Line 2.

3. Magnetic signal amplitude of ~5 nT due to the combine effect of a swinging magnetometer through a high-gradient geomagnetic field and the large acceleration experienced in pitch transitioning from hovering to traverse. Represented in the magnetic data in at A.
Conclusions

1. Magnetic signal amplitude of $\sim 2 \text{ nT}$ due to the swinging of the magnetometer in sharp corners. Represented in the magnetic data at C & D.

2. Magnetic signal amplitude of $\sim 3 \text{ nT}$ due to the swinging of the magnetometer through a high-gradient geomagnetic field. Represented in the magnetic data at Flight Line 1 and Flight Line 2.

3. Magnetic signal amplitude of $\sim 5 \text{ nT}$ due to the combine effect of a swinging magnetometer through a high-gradient geomagnetic field and the large acceleration experienced in pitch transitioning from hovering to traverse. Represented in the magnetic data in at A.
Conclusions

4. Magnetic signal amplitude of $< 1$ nT due to low amplitude swinging ($< 10^\circ$) of the magnetometer through the low-gradient geomagnetic field. Represented in the magnetic data at position B during the wide turn.

5. The swinging amplitude of the magnetometer in the roll axis down flight lines at a constant speed of 7.5 m/s is steady at $\sim 5^\circ$. Represented in the magnetometer roll data at Flight Line 1 and Flight Line 2.
Conclusions

6. There are two, non-exclusive causes to the larger swinging signals: (1) swinging signal due to cornering or larger accelerations experienced by the magnetometer during flight maneuvers and (2) swinging signals due to magnetometer movement through larger-gradient geomagnetic field.

7. The ~0.3 Hz swinging signal in the RMI data were characterized and removed from the longer wavelength geological signals due to the two wavelengths not spectrally overlapping.

Acknowledgements