High Performance Attitude Determination through Analysis of Geometric Distortions within Earth Observational Satellite Imagery

David C. Bamber

Supervisors: Dr Mackin & Dr Palmer
Content

- Introduction
- Conventional sensors
- Attitude determination with DMC
- Model
- Accuracies
- Results
- Conclusion
Introduction

- Images captured by 2 different cameras onboard the same satellite
- Narrow angle between cameras causes each sensor to view different areas of ground
- Both images sectioned and registered
- Found periodic oscillation in row shift
- Oscillation correlates with onboard vibration
Attitude sensors

Current sensors

- Magnetometer
- GPS
- Sun Sensor
- Earth horizon sensor
- Star field sensor

Accuracy + Cost increase

All measure rotations relative to reference
Proposed technique

Uses Earth as reference with imaging payload as attitude sensor

Benefits

- Measures orientation + rates over 3 axis
- Low cost and mass
- High accuracies
Attitude determination using DMC imagery

Disaster Monitoring Constellation (DMC)

Constellation of 5 satellites with 24-hour revisit

DMC has 3 pushbroom imager pairs

Each pair is angled to give 600 km swath + 16km overlap with 1 imager projected ahead of the other

Passing features will register at different points along each array with time delay

With different attitude, features will register at different parts of trailing sensor
Attitude determination using DMC imagery

DMC Images

- Projection of features further along array gives column shift

- Changes in time-delay affects row shift
Model

- Vectors used to model DMC cameras
- Attitude and rates applied to model to discern changes in row & column shift for each pixel

\[
\psi_C(\gamma_1) = f(\tan \gamma_2 - \tan \gamma_1) \quad \psi_R(\gamma_1) = \frac{\Delta T}{L_D}
\]

\[
\Delta T = \frac{(\vec{S}(\gamma_1) \cdot \hat{q})}{(\vec{V} \cdot \hat{q})} \quad \cos \gamma_2 = \frac{(\vec{P}(\gamma_2) \cdot \hat{X}_v)}{|\vec{P}(\gamma_2)_o|}
\]

\[
\vec{P}(\gamma_2) = \vec{S}(\gamma_1) - \vec{V} \Delta T
\]

**Inversion:** Row + column shift \(\rightarrow\) Satellite attitude

2006-8-25

David C. Bamber
Simulated Accuracies

Using DMC (32m) + 0.1 pixel registration

<table>
<thead>
<tr>
<th>Manoeuvre</th>
<th>Attitude</th>
<th>Rates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Yaw</td>
<td>2 arcmin</td>
<td>7 arcsec</td>
</tr>
<tr>
<td>Pitch</td>
<td>5 arcmin</td>
<td>1 arcsec</td>
</tr>
<tr>
<td>Roll</td>
<td>3 arcmin</td>
<td>1 arcsec</td>
</tr>
</tbody>
</table>

- Distinguish 3-axis attitude or rates
- Technique is x100 more sensitive to rates
- Accuracies dependant on camera + registration
- Sampling rates > 15 Hz
Results – Yaw

Yaw Drift

In order to test the model the UK-DMC was allowed to drift in yaw during an image run.

Results:
- ADCS shows 7 degree yaw occurred
- Image based yaw estimates agree with ADCS
- 0.96 correlation coefficient
Results – Pitch oscillation

Onboard vibration
Model inversions used to convert image shifts to rate data

Results:
- Presence of onboard vibration confirmed
- Amplitude – 30 arcsec
- Frequency – 0.6 Hz
DMC Wheel activation

In order to find cause of pitch oscillations both wheels were turned off, with Y-wheel being reactivated near start of image run.

Results:

- Row shift began oscillating at similar frequency
- Oscillation amplitude slowly decays
- Minimum amplitude is 5 arcsec/sec
Summary

Advantages

- Discerns attitude position and rates over 3 axes
- High accuracies & frequent acquisition rates
- Off-shelf components allow for low costs and mass

Disadvantages

- Attitude position and rates need decoupling
- Image texture dependence - limits accuracy and orbital coverage
- Onboard power consumption and processing requirements unknown
Conclusion

- Novel method for 3 axes attitude determination identified
- Simulated accuracies prove competitive
- Experimental results support technique
- With further study the potential of this technique may be realised
Thank you

For further information contact:
David Bamber - Surrey Space Centre
University of Surrey, Guildford, Surrey, GU2 7XH,
Email: d.bamber@surrey.ac.uk