SMARTScan – Smart Pushbroom Imaging System for Shaky Space Platforms

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Contents:
- Problem Definition
- SMARTSCAN Principle
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Problem definition

Satellite attitude motion effects on pushbroom camera

- **Attitude Instability**
  - In flight direction
  - Perpendicular to the flight direction
  - Distance, pixels
  - Time, line exposure intervals

- **Non-parallel Scanning**
  - Distance, pixels
  - Time, line exposure intervals

- **Stable Image Motion**
  - In flight direction
  - Perpendicular to the flight direction

- **Disturbed Image Motion**
  - In flight direction
  - Perpendicular to the flight direction
  - Simulated images (10 lines TDI)
Solution: SMARTSCAN – image motion compensation

Features

• **in-situ** focal plane image motion measurement
• **posteriori** motion compensation
• allows less costly remote sensing from simple platforms
Image motion tracking by 2D correlation

2D correlation

- weakly structured image texture (no features used!)
- robustness to small signal-to-noise ratio
- high computational effort

Focal Plane Area Sensor

image 1 \( t=t_1 \)

image motion

image 2 \( t=t_2 \)

2D Correlation

image shift vector \( \vec{S} \)

Camera Focal Plane

Area sensors

Image Motion Measurement

image shift vectors \( \vec{S}_i \)

Linear Sensor

raw image data (linear sensor)

Flight direction
JTOC – Joint Transform Optical Correlator

\[ S_{CCD_1}(u, v) = |F\{I_1(x, y) + I_2(x, y)\}|^2\]

\[ S_{CCD_2}(l, m) = |F\{S_{CCD_1}(u, v)\}|^2 = |I_1(x, y) \otimes I_2(x, y)|^2\]

Image 1  Image 2

\(I_1(x, y) + I_2(x, y)\)

input image(s)

\(S_{CCD_1}(u, v)\)

spectrum image

\(S_{CCD_2}(l, m)\)

correlation image

Optical Fourier Processor 1

Optical Fourier Processor 2

JTOC

60 corr./sec.

JTOC – Accuracy & Robustness

**Subpixel Image Shift Measurement**

Image 1

Image 2

**Correlation function**

\[ c_{i,j} = \sum_{n,m} a_{n,m} \cdot b_{n+i,m+j} \]

**Correlation maximum**

\[ D = D_0 + E \]

\[ E = (e_x, e_y) \]

**Measurement Error**

**subpixel accuracy**

**Image Noise**

**Window Size**

- RMS error, pixels
- Signal to noise ratio, dB
- Horizontal, vertical

- RSS of RMS error, pixels
- Image size, pixels
- 80x60, 120x80, 160x120, 240x160
JTOC – Accuracy & Robustness

Subpixel Image Shift Measurement

Correlation function \( C_{i,j} = \sum_{m} \sum_{n} a_{n,m} \cdot b_{n+i,m+j} \)

Image 1

D

Image 2

Correlation maximum

\( D = D_0 + E \)

\( E = (e_x, e_y) \)

Measurement Error

JTOC

block size 128x128 pixels

greyscale 0...255

random additive image noise

20 greyscale bit (1\( \sigma \))

\( \rightarrow \) subpixel accuracy

Image Noise

Window Size

Test image | Successful correlations | Standard deviation of error [pixels]
---|---|---
Urban scene (A) | 100.0\% | 0.0127
Rural scene (B) | 91.9\% | 0.0166
Mountain with snow and clouds (C) | 93.1\% | 0.0332
Water surface with waves (D) | 98.2\% | 0.0062
Water surface w/o waves (E) | 28.6\% | 0.1061
**SMARTScan breadboard**

**Camera breadboard**

<table>
<thead>
<tr>
<th>Lens</th>
<th>Tessar type: ( f = 75 \text{ mm}; f/4 ); angular resolution - 187 ( \mu \text{rad/pixel} )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Linear sensor</td>
<td>Resolution: 2048 pixels in line; lines rate: 240 lines per second</td>
</tr>
<tr>
<td>Auxiliary matrix sensors</td>
<td>Frame size: 640 x 480 pixels; frames rate: 30 frames per second</td>
</tr>
<tr>
<td>Dimensions / mass</td>
<td>110 x 58 x 50 mm / 900 g</td>
</tr>
</tbody>
</table>

**Optical correlator breadboard**

- 60 correlations per second
- Input – two video streams
- Output – image motion record
- Double optical unit
- Self-calibration
Airborne Test

- Altitude: 2400 m
- Velocity: 240 km/h = 66.7 m/s
- Ground resolution: 0.45 m/pixel

Camera mount (suppresses vibrations above 10 Hz)
Airborne Test Results

Image motion (pixels)

Ideal IMR in the flight direction

Real IMR in the flight direction

Real IMR perpendicular to the flight direction

Number of the line
Airborne Test Results

- Original (distorted) image
- Corrected image

2D-correlator

Image Motion
Time History

+ Image Correction
Airborne Test Results

Original (distorted) image  

2D-correlator

Image Motion
Time History

+ Image Correction

Corrected image
Conclusions & Outlook

Achieved

• **SMARTSCAN** principle successfully demonstrated

• **method:** image motion tracking using 2D-correlation

• **key technology:** embedded optical correlator, in-flight tested

• **application:** high accuracy imaging from shaky platforms
Conclusions & Outlook

Achieved

• **SMARTSCAN** principle successfully demonstrated
• *method*: **image motion tracking** using 2D-correlation
• *key technology*: embedded **optical correlator**, in-flight tested
• *application*: **high accuracy imaging** from shaky platforms

Next Steps

• **advanced optical correlator** development
• **space qualification** of OC technology
-- end of presentation --

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