Airborne digital sensors: principles, design and use as exemplified by the LH Systems ADS40

Peter Fricker, Felix Zuberbühler & Roger Pacey

3 January 2001
Contents

- An ADS image sequence taken with the engineering model
- Airborne sensor application segments
- Principle of the pushbroom scanner ADS40 and differences to the film frame camera RC30
- The Airborne Digital Sensor ADS40
- The three-line principle, ground processing and digital workflow
ADS image - Berlin-Alexanderplatz ~ 1:70,000

Airborne
Digital
Sensor:
engineering
model

Flying height:
9,840 ft.
3,000 m

Ground sample distance:
GSD ≈ 25 cm

Date:
23 April 1999
ADS image - Berlin-Alexanderplatz ~ 1:35,000

- **Airborne Digital Sensor:** engineering model
- **Flying height:** 9,840 ft. (3,000 m)
- **Ground sample distance:** GSD ≈ 25 cm
- **Date:** 23 April 1999
ADS image - Berlin-Alexanderplatz ~ 1:17,500

Airborne Digital Sensor: engineering model

Flying height:
9,840 ft.
3,000 m

Ground sample distance:
GSD ≈ 25 cm

Date:
23 April 1999
ADS image - Berlin-Alexanderplatz ~ 1:8,000

Airborne Digital Sensor: engineering model

Flying height: 9,840 ft.
3,000 m

Ground sample distance: GSD ≈ 25 cm

Date: 23 April 1999
Airborne
Digital
Sensor:
engineering
model

Flying height:
9,840 ft.
3,000 m

Ground sample distance:
GSD ≈ 25 cm

Date:
23 April 1999
ADS image - Berlin-Alexanderplatz ~ 1:2,000

Airborne Digital Sensor: engineering model

Flying height:
9,840 ft.
3,000 m

Ground sample distance:
GSD ≈ 25 cm

Date:
23 April 1999
ADS image - Berlin-Alexanderplatz ~ 1:1,000

Airborne Digital Sensor: engineering model

Flying height: 9,840 ft. 3,000 m

Ground sample distance: GSD \approx 25 \text{ cm}

Date: 23 April 1999
ADS image - Berlin-Alexanderplatz ~ 1:500

Airborne Digital Sensor: engineering model

Flying height: 9,840 ft. 3,000 m

Ground sample distance: GSD ≈ 25 cm

Date: 23 April 1999
ADS40 - Rectified RGB image (Fast Level 1)

Airborne Digital Sensor:
series 0 model

Flying height:
6,080 ft.
1,850 m

Ground sample distance:
GSD ≈ 20 cm

Date:
7 July 2000
Radiometry

Reichstag, Berlin  23 April 1999

Flying height
9,840 ft/ 3,000 m
GSD \approx 25 \text{ cm}

Detail in high reflectance area

Detail in low reflectance area
Airborne sensor application segments
Airborne sensor application segments

- Earth Resources
- Agriculture
- Forestry
- Defense
- Environment
- Transportation
- Urban
- Topographic Mapping

Panchromatic
Multispectral
Hyperspectral

Spatial Resolution
100 m  10 m  1 m  0.1 m  0.01 m

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Applications covered by the ADS40

- Earth Resources
- Agriculture
- Forestry
- Defense
- Environment
- Transportation
- Urban
- Topographic Mapping

Spectral Resolution

- Panchromatic
- Multispectral
- Hyperspectral

Spatial Resolution

- 100 m
- 10 m
- 1 m
- 0.1 m
- 0.01 m
Resolution - interpretation - identification
Resolution - interpretation - identification

12.8m

6.4m.

3.2m

1.6m

0.80m

0.40m

0.20m

0.10m
Resolution - interpretation - identification

1.6m

0.80m

0.40m

0.20m

0.10m

0.05m

0.03m

0.01m
Resolution - interpretation - identification

**GSD 1.6m**

Size of recognizable object
GSD x 3

Car size ~ 4.5m - 5m
GSD 1.6 m x 3 = 4.8 m

**GSD 0.20m**

Size of interpretable object
GSD x 21

Car size ~ 4.5 - 5m
GSD 0.2 m x 21 = 4.8 m
Airborne and Spaceborne imagery

**Spaceborne Sensors**
- 800 km / 500 miles
- 400 km / 250 miles
- 1.3 million ft to 2.5 million ft
- 400,000 m to 760,000 m
- GSD > 0.80m

**Airborne Sensors**
- 12 km / 40,000 ft
- 1 km / 3,000 ft
- 1.3 million ft to 40,000 ft

**Airborne Digital**
- GSD 0.20m

**Airborne Film**
- GSD 0.10m
## Complementing strengths of airborne vs. spaceborne

<table>
<thead>
<tr>
<th>Airborne digital sensors</th>
<th>Spaceborne sensors (Hi-Resolution)</th>
</tr>
</thead>
<tbody>
<tr>
<td>■ Data on demand</td>
<td>■ Fixed orbit (650 km)</td>
</tr>
<tr>
<td>■ Can operate in adverse weather conditions (flying under clouds)</td>
<td>■ Availability is weather dependent</td>
</tr>
<tr>
<td>■ Adaptable resolution 0.1 - 0.8 m Pan 0.2 - 1.6 m Multispectral by changing flying height</td>
<td>■ Fixed resolution 1m Pan 4m Multispectral</td>
</tr>
<tr>
<td>■ Stereo imagery is inherent</td>
<td>■ Known cost per scene</td>
</tr>
<tr>
<td></td>
<td>■ Stereo on demand</td>
</tr>
</tbody>
</table>
Comparison of images

**ADS Engineering Model**

**IKONOS**
Comparison of resolution

ADS Engineering Model
12,000 pixels

IKONOS
Principle of pushbroom scanner ADS40

Differences to film frame camera RC30

and surface array technology
Terminology

### Airborne digital sensor
**ADS40**

**Example**
- **Pixel on CCD**: 6.5 x 6.5 μm
- **Field of view across track**: FoV 64°
- **Swath**: 2.4 km
- **Ground sample distance, GSD**: 20 cm

### Analog aerial camera
**RC30**

**Example**
- **Image size**: 228 mm x 228 mm
- **Focal length**: 153 mm
- **Footprint**: 2.4 km x 2.4 km
- **Photo scale**: 1 : 10,500
Three-line pushbroom scanner

Backward scene composed of backward view lines

Nadir scene composed of nadir view lines

Forward scene composed of forward view lines
Swath width of different sensors at same GSD

**ADS40**
- GSD: ~ 20cm
- Swath: ~ 2.4 km
- Flight lines: 1

**Typical digital frame camera**
- GSD: ~ 20cm
- Swath: ~ 0.9 km
- Flight lines: 3

Swath width of ADS40 with 2x12k staggered CCD lines
Swath of 4K surface array camera
Different imaging concepts of ADS40 and RC30

Airborne digital sensor ADS40
- continuous pushbroom scanning
- forward view
- nadir view
- backward view

Analog aerial camera RC30
- discrete perspective images
- overlapping aerial photographs
Image overlap

Airborne digital sensor ADS40

All objects recorded 3 times

Analog aerial camera RC30

Not all objects recorded 3 times

Flying with 60% overlap only 60% of all objects are on 3 photographs
Effect of central perspective

**Airborne digital sensor ADS40**
- Forward view strip
- Nadir view strip
- Backward view strip

**Analog aerial camera RC30**
- Photograph with central perspective
- Flight line with overlapping photographs
Forward motion compensation

**Pushbroom line scanner**  
**ADS40**

Integration time of CCD line is always less than time needed to fly GSD

*Typical example*
- SOG 100 kts
- Swath 2.4 km
- GSD ~20 cm
- Integration time 1.2 ms
- Image motion ~2 μm

Forward motion of aircraft during integration (‘exposure’) can be ignored

**Frame aerial camera, film based or digital**

Long exposure time for film  
Long integration time of CCD array

*Typical example*
- SOG 100 kts
- Swath 2.4 km
- Mb ~1:10,500
- Exposure time 1/200 s
- Image motion ~24 μm

Forward motion of aircraft during exposure or integration should be compensated.
# Diaphragm setting

<table>
<thead>
<tr>
<th><strong>Airborne digital sensor</strong>&lt;br&gt;<strong>ADS40</strong></th>
<th><strong>Analog aerial camera</strong>&lt;br&gt;<strong>RC30</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Always at full aperture f/4 not adjustable</td>
<td>Typical full aperture f/4 adjustable from f/4 to f/22</td>
</tr>
</tbody>
</table>

**Reasons for fixed diaphragm setting:**
- To obtain perfect digital images under different light conditions, variation of integration time only is sufficient.
- Best digital images can be obtained only if lens performance is perfectly adapted to the CCD. This is the case at f/4.

**Reasons for setting other than f/4:**
- To obtain perfectly exposed photographs under different light conditions on various film types.
- To increase optical performance on older lens-types by closing one f-stop.
# Drift setting

## Airborne digital sensor ADS40

- Automatic drift setting by Flight & Sensor Control Management System (FCMS)
- FCMS computes value based on track over ground from GPS and heading information from IMU

## Analog aerial camera RC30

- Set by operator on Navigation Sight
- Optionally: Derived from aircraft navigation system
With CCD sensors it is possible to measure incoming photons in absolute linear values.
Filter transmission for the ADS40 is clearly defined while the sensitivity of film layers overlap and dyes forming the image have color contamination.
Filter transmission characteristics

Interference filters
Used in ADS40

Absorption filters
Used in CCD array cameras

Non-overlapping narrow bands

Overlapping bands

Only interference filters are suitable for remote sensing applications where response in non-overlapping narrow bands is evaluated.
Spectral band filters

Legend
1 Grass
2 Lime Stone
3 Sand, dry
4 Snow, old
5 Fir tree
6 Asphalt, wet
7 Water
Panchromatic filter

Legend
1 Grass
2 Lime Stone
3 Sand, dry
4 Snow, old
5 Fir tree
6 Asphalt, wet
7 Water
Calibration

Pushbroom line scanner
ADS40

- Geometric calibration
- Radiometric calibration

Frame aerial camera,
film based or digital

- Film based
  - Geometric calibration
  - Radiometric calibration
- Digital
  - Geometric calibration
  - Radiometric calibration

720k calibration data for geometric and radiometric calibration of ADS40

About 1,000 x more calibration data are needed for an equivalent digital frame sensor
Defective pixels on CCD

Pushbroom line scanner
ADS40

Digital frame camera

Frame sensors typically have defective half lines and also faulty single pixels randomly distributed over the CCD frame.

ADS40 digital sensor has CCD lines with no defective pixels.
Dynamic range of CCD chain of ADS40: 12 bit = 4096 steps

Dynamic range of normalized data: 8 bit = 256 steps

Offset and normalized data represent data of 12 bit dynamic range
Data normalization

Dynamic range of CCD chain of ADS40: 12 Bit = 4096 steps

Dynamic range of normalized data: 8 Bit = 256 steps

Offset and normalized data represent data of 12 Bit dynamic range
# Decimal & Binary - Bits & Bytes

<table>
<thead>
<tr>
<th>Decimal</th>
<th>Binary</th>
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<tr>
<td>0</td>
<td>0 1</td>
</tr>
<tr>
<td>1</td>
<td>1 1</td>
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<tr>
<td>2</td>
<td>1 0 2</td>
</tr>
<tr>
<td>3</td>
<td>1 1 2</td>
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<tr>
<td>4</td>
<td>1 0 0 3</td>
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<td>5</td>
<td>1 0 1 3</td>
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<td>6</td>
<td>1 1 0 3</td>
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<td>7</td>
<td>1 1 1 3</td>
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<td>15</td>
<td>1 1 1 1 4</td>
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<td>31</td>
<td>1 1 1 1 5</td>
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<td>63</td>
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<tr>
<td>127</td>
<td>1 1 1 1 1 1 7</td>
</tr>
<tr>
<td>255</td>
<td>1 1 1 1 1 1 1 8</td>
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</table>

<table>
<thead>
<tr>
<th>8 Bits</th>
<th>= 1 Byte</th>
</tr>
</thead>
<tbody>
<tr>
<td>$2^{10}$ Bytes</td>
<td>= 1024 Bytes = 1 KB</td>
</tr>
<tr>
<td>$2^{10}$ KB</td>
<td>= 1024 KB = 1 MB</td>
</tr>
<tr>
<td>$2^{10}$ MB</td>
<td>= 1024 MB = 1 GB</td>
</tr>
<tr>
<td>$2^{10}$ GB</td>
<td>= 1024 GB = 1 TB</td>
</tr>
<tr>
<td>$2^{10}$ TB</td>
<td>= 1024 TB = 1 PB</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Abbreviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>KB = Kilo Bytes</td>
</tr>
<tr>
<td>MB = Mega Bytes</td>
</tr>
<tr>
<td>GB = Giga Bytes</td>
</tr>
<tr>
<td>TB = Tera Bytes</td>
</tr>
<tr>
<td>PB = Peta Bytes</td>
</tr>
</tbody>
</table>
Panchromatic and spectral band filters
Three-line principle for stereo imaging

- Forward strip
- Nadir strip
- Backward strip

Different area from same sensor location

Same area from different sensor locations (viewing angles)
Workflow - film based and direct digital

Film based workflow
RC30

Film processing in darkroom
B&W
Color
FCIR

Films alternatively

Stereo plotter
DSW500 scanner

Direct digital workflow
ADS40

Mass Memory

Ground processing

Digital work-station

Printer

Spectral channels simultaneously

Workflow - film based and direct digital

DTM
Orthophotos
Mapping
Revision
Visualization
Image analysis
Classification

GIS

Workflow - film based and direct digital

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Meeting, Place, Country • 1 December 2000 • Airborne digital sensors: principles, design and use as exemplified by the LH Systems ADS40
### Equivalence

<table>
<thead>
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<th>Airborne digital sensor</th>
<th>Analog aerial camera</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADS40</td>
<td>RC30</td>
</tr>
</tbody>
</table>

- Image recorded with lines of 24,000 staggered pixels
- Photograph scanned with 12.5 µm
- For a map with scale of 1:1,500
  - … digital images with a GSD of 15 - 20 cm are needed
  - …. photos with a scale of a 1:8,000 - 1:12,000 are needed
### Map scale for digital images

<table>
<thead>
<tr>
<th>Airborne digital sensor</th>
<th>ADS40</th>
<th>Airborne digital sensor</th>
<th>ADS40</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Image Pixel = 0.1mm in Map</td>
<td>1 Image Pixel = 15cm GSD</td>
<td>1 Image Pixel = 4 mil in Map</td>
<td>1 Image Pixel = 1/2 ft GSD</td>
</tr>
<tr>
<td>Scale equivalent</td>
<td></td>
<td>Scale equivalent</td>
<td></td>
</tr>
<tr>
<td>1 Pixel Map : 1 Pixel Ground</td>
<td></td>
<td>1 Pixel Map : 1 Pixel Ground</td>
<td></td>
</tr>
<tr>
<td>0.1mm : 150mm</td>
<td></td>
<td>4 mil : 1/2 ft</td>
<td></td>
</tr>
<tr>
<td>1 : 1,500</td>
<td></td>
<td>1 : 1,500</td>
<td></td>
</tr>
</tbody>
</table>
Accuracy

Airborne digital sensor ADS40

Best achievable geo-referencing accuracy

~ 10 cm x, y, z

at GSD 15 cm

Analog aerial camera RC30

Best achievable point accuracy

~ 3-4 cm x, y, z

at photo scale 1:1,500
Benefits and differences

<table>
<thead>
<tr>
<th>Airborne digital sensor ADS40</th>
<th>Analog aerial camera RC30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Three in one: b&amp;w, color, and false color sensor</td>
<td>Well known established products</td>
</tr>
<tr>
<td>Simple and precise co-registration of multi-spectral data</td>
<td>Highest resolution</td>
</tr>
<tr>
<td>Savings in photo lab and scanning processes</td>
<td>Lower flying heights</td>
</tr>
<tr>
<td>Reduced ground control</td>
<td>Variable stereo angles</td>
</tr>
<tr>
<td>Complete digital workflow</td>
<td></td>
</tr>
</tbody>
</table>

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Deutsches Zentrum für Luft- und Raumfahrt (DLR) - the German Aerospace Center - has many years of experience with three-line stereo scanners for space and airborne applications.

Well known, one-of-a-kind experimental sensors such as the WAOSS, WAAC, MOS, MOMS, HRSC and DPA were all developed in Germany.
ADS40 development - by LH Systems and DLR

Partnership of

LH Systems + DLR (German Aerospace Center) = Airborne Digital Sensor

LH Systems + DLR = ADS40
Airborne ADS40 system

ADS40 System
1. Sensor head SH40 with:
   - Digital optics DO64
   - IMU
2. Control unit CU40 with:
   - position & attitude computer POS
3. Mass Memory MM40
4. Operator interface OI40
5. Pilot Interface PI40
6. Mount PAV30
Airborne digital sensor
Main features of the ADS40

- High area coverage performance (FoV, swath)
- High resolution and accuracy (spatial and radiometric)
- Multispectral imagery
- Linear sensor characteristics
- Stereo capability
- Direct digital workflow
- Affordable, application oriented sensors
IMU integrated in Sensor Head SH40
GPS integrated in Control Unit CU40
FCMS Flight Control Management System (software)
POS Position and Attitude Computer integrated in CU40
PAV30 gyro-stabilized mount (not part of standard delivery)
Sensor Head SH40

- 3 panchromatic CCD lines each 2 x 12,000 pixels, staggered by 3.25 µm
- 4 multispectral CCD lines, each 12,000 pixels
- Pixel size: 6.5 µm x 6.5 µm
- Field of view (FoV) or swath angle: 64°
- Focal length: 62.77 mm
- Stereo angles: 14°, 28°, 42°
Sensor Head SH40

- IMU
- Focal plate
- Lens
- Front cover glass
- Electronics
- Heating and Cooling System
- Filters & Trichroid
- Video Camera
- 64° large FoV (Swath angle)
- f-number: 4
- 420-900 nm spectral range
- Resolution ~ 150 lp/mm
- Registration accuracy 1 μm
- Thermic & pressure stabilization in high accuracy range from +10°C to +30°C

Telecentric design
- Maintains position and width of all filter edges over the whole FoV
Telecentric optics design

Telecentric optics design
ADS40

Vertical incidence of all ray bundles

Object space Image space
Interference filter and Trichroid can be used

Conventional optics design

Vertical incidence only for ray bundle on the optical axis

Object space Image space
Absorption filters must be used. NOT suitable for remote sensing applications
Spectral transmission of interference filters

Telecentric optics design
ADS40

Interference filter transmission equal across whole FoV

Conventional optics design

Interference filter transmission not equal for whole FoV

Suitable for remote sensing

Not suitable for remote sensing
- Optical RGB pixel co-registration device
- Cascaded dichroitic beam splitters
- Energy conservation due to spectral light splitting
- Metal interference filters
- Between optics and CCDs
Temperature controlled focal plate

Focal plate

- The “heart” of the ADS40
- 2 single and 2 triple CCD devices with 7 channels
- 3 panchromatic channels, each with 2 x 12K elements in a staggered arrangement
- 4 multispectral channels, R,G,B,NIR each with 12K elements
- Peltier cooling system
Benefits of asymmetry

- Choice of various stereo angles 14.2°, 28.4°, 42.6°
- No singularity in mathematical formulae used in adjustment processes
Features

- All RGB channels with same incidence angle due to co-registration by Trichroid
- NIR channel close to nadir
Staggered panchromatic CCD lines

**Staggered CCD line**
- Two CCD lines with 12K. Across track offset ½ pixel
- No aliasing effects
- Rectified Images
- High-Resolution Level 1
- Siemens Star diameter 8 m

**Single CCD line**
- One CCD line with 12K
- Aliasing effects
- Rectified Images
- Level 1
- Siemens Star diameter 8 m
Application of staggered CCD line

For high panchromatic resolution with the ADS40 the area of $\frac{1}{2}$ GSD is computed from 4 different recordings. That is, each recording takes place at 2 locations in each staggered CCD. To achieve this:

- The readout rate is at $\frac{1}{2}$ GSD in flight direction
- $\frac{1}{2}$ GSD offset across track is obtained with staggered CCD
- Applanix POS System
- OEM version integrated into Sensor Head SH40
- Tight IMU/GPS integration
- High short term IMU attitude accuracy, $\sigma < 4''$ after linear correction
- 200 Hz IMU readout frequency
The GPS sensor generates an absolute position at 2 Hz
The IMU sensor generates a relative position and a precise orientation of pitch, roll and drift at 200 Hz
Trajectory given by IMU is updated with absolute position given by GPS.
The post-processed trajectory is then interpolated to generate position & orientation at 800 Hz (1.2 ms interval)
Control Unit CU40

- Fiber optics link to SH40
- Integrated POS system
- Integrated GPS receiver
- High data throughput to MM40 up to 45 MB/sec
- Windows NT Embedded OS with Realtime extensions
Mass Memory MM40

- Disk array 216 MB or 438 MB
- Exchangeable between flight lines
- Portable, 23 kg
- Pressurized, 25,000 ft
- Temperature control
- Shock mounted

Sealing

Hard disks

Hermetic Connector

Shock mounts
## Data

<table>
<thead>
<tr>
<th>Data name</th>
<th>Data definition</th>
<th>Compression factor on ADS data</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADS data</td>
<td>Normalized &amp; loss-less compacted</td>
<td>1x</td>
</tr>
<tr>
<td>ADS data compressed</td>
<td>(Normalized &amp; loss-less compacted) &amp; JPEG compressed</td>
<td>2.5x</td>
</tr>
<tr>
<td>ADS data compressed (limit)</td>
<td>(Normalized &amp; loss-less compacted) &amp; JPEG compressed</td>
<td>25x</td>
</tr>
<tr>
<td>ADS raw data</td>
<td>Raw data 12 bit/pixel stored in 2 bytes</td>
<td>0.25x</td>
</tr>
</tbody>
</table>
Data volume on MM recorded in ADS data format

<table>
<thead>
<tr>
<th>Line length</th>
<th>GB</th>
</tr>
</thead>
<tbody>
<tr>
<td>Line length</td>
<td>200</td>
</tr>
<tr>
<td>MM40-438</td>
<td></td>
</tr>
<tr>
<td>GB</td>
<td>200</td>
</tr>
<tr>
<td>GSD 15cm (~1/2ft), Swath 3.6km (2.24mi), Height 2880m (9450ft)</td>
<td></td>
</tr>
<tr>
<td>GSD 20cm (~2/3ft), Swath 4.8km (3.0mi), Height 3840m (12500ft)</td>
<td></td>
</tr>
<tr>
<td>GSD 30cm (~1ft), Swath 7.2km (4.5mi), Height 5760m (18900ft)</td>
<td></td>
</tr>
<tr>
<td>GSD 45cm (~1/2ft), Swath 7.2km (4.5mi), Height 5760m (18900ft)</td>
<td></td>
</tr>
<tr>
<td>GSD 50cm (~1/2ft), Swath 12km (7.5mi), Height 9600m (31500ft)</td>
<td></td>
</tr>
<tr>
<td>GSD 50cm (~1/2ft), Swath 12km (7.5mi), Height 9600m (31500ft)</td>
<td></td>
</tr>
<tr>
<td>GSD 50cm (~1/2ft), Swath 12km (7.5mi), Height 9600m (31500ft)</td>
<td></td>
</tr>
<tr>
<td>3 pan &amp; 4 multi-spectral</td>
<td></td>
</tr>
<tr>
<td>3 pan only</td>
<td></td>
</tr>
<tr>
<td>1 pan &amp; 3 multi-spectral</td>
<td></td>
</tr>
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</table>

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### Area stored on MM

#### MM40-216

<table>
<thead>
<tr>
<th>Configuration</th>
<th>GSD cm</th>
<th>GSD ft</th>
<th>Area km²</th>
<th>Area mi²</th>
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<tbody>
<tr>
<td><strong>3 Pan 4 MS</strong></td>
<td>15</td>
<td>1/2</td>
<td>1,908</td>
<td>737</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2/3</td>
<td>3,447</td>
<td>1,331</td>
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<td></td>
<td>30</td>
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<td>8,070</td>
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<td>29,274</td>
<td>11,303</td>
</tr>
<tr>
<td><strong>1 Pan 3 MS</strong></td>
<td>15</td>
<td>1/2</td>
<td>4,457</td>
<td>1,721</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2/3</td>
<td>8,294</td>
<td>3,202</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1</td>
<td>18,097</td>
<td>6,987</td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>1 1/2</td>
<td>58,549</td>
<td>22,606</td>
</tr>
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</table>

#### MM40-438

<table>
<thead>
<tr>
<th>Configuration</th>
<th>GSD cm</th>
<th>GSD ft</th>
<th>Area km²</th>
<th>Area mi²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>3 Pan 4 MS</strong></td>
<td>15</td>
<td>1/2</td>
<td>3,868</td>
<td>1,494</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2/3</td>
<td>6,989</td>
<td>2,699</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>1</td>
<td>16,365</td>
<td>6,318</td>
</tr>
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<td></td>
<td>50</td>
<td>1 1/2</td>
<td>45,871</td>
<td>17,711</td>
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<tr>
<td><strong>3 Pan only</strong></td>
<td>15</td>
<td>1/2</td>
<td>5,298</td>
<td>2,046</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2/3</td>
<td>10,485</td>
<td>4,048</td>
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<td></td>
<td>30</td>
<td>1</td>
<td>21,625</td>
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<td></td>
<td>50</td>
<td>1 1/2</td>
<td>59,362</td>
<td>22,920</td>
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<tr>
<td><strong>1 Pan 3 MS</strong></td>
<td>15</td>
<td>1/2</td>
<td>9,037</td>
<td>3,489</td>
</tr>
<tr>
<td></td>
<td>20</td>
<td>2/3</td>
<td>16,819</td>
<td>6,494</td>
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<tr>
<td></td>
<td>30</td>
<td>1</td>
<td>36,696</td>
<td>14,169</td>
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<tr>
<td></td>
<td>50</td>
<td>1 1/2</td>
<td>118,724</td>
<td>45,840</td>
</tr>
</tbody>
</table>

**ADS data format, square area flown with 20% side lap**
Data storage in ADS system

- IMU data
- GPS data

- Image data
- Housekeeping data

- Flight data
- Project data

- FCMS log data
- Error messages

Mass Memory
- MM40

Hard disk
- in CU40
Operator Interface - OI40

- High contrast, LCD color pressure sensitive touch screen
- 1024 x 768 pixels
- Ergonomic positioning
- Shock absorbing suspension
- Removable
- OI40 mounts onto Interface stand IS40
- IS40 has its own base or fits into PAS12 base of RC30 Navigation Sight
Flight & Sensor Control Management System

- Flight guidance
- Sensor control
- System management
- Graphical user interface
- Online help system
- Self diagnostics
Graphical user interface

- Figurative language on large buttons
- Simple touch screen interface
- Pre-defined system configurations
- Quick navigation within the menu-tree
- System fully configurable for different users
- Easy to learn operation
- Integrated tutorial
### FCMS - ADS40 system status

<table>
<thead>
<tr>
<th>ADS 40</th>
<th>RC 30</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Diagram of ADS 40 system" /></td>
<td><img src="image2" alt="Diagram of RC 30 system" /></td>
</tr>
</tbody>
</table>

- **ADS 40**
  - 184 GB
  - 1:48 h
  - 266 GB
  - 2:19 h

- **ADS 40**
  - 3DD
  - 7 Sats
  - G Dop 5.5
  - H Dop 8.1

- **2.50 GB**
  - 7:52 h

- **June 22, 2000**
  - 15:34:35 h

© 2000 LH Systems, LLC
<table>
<thead>
<tr>
<th>Pan</th>
<th>Spectral</th>
<th>Swath - Pan</th>
<th>Swath - Spectral</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>ON/OFF</strong></td>
<td><img src="https://via.placeholder.com/150" alt="Image" /></td>
<td><img src="https://via.placeholder.com/150" alt="Image" /></td>
<td><img src="https://via.placeholder.com/150" alt="Image" /></td>
</tr>
<tr>
<td>Image pixel size</td>
<td>6.50 µm</td>
<td></td>
<td><img src="https://via.placeholder.com/150" alt="Image" /></td>
</tr>
<tr>
<td>Ground pixel size</td>
<td>24 cm</td>
<td></td>
<td><img src="https://via.placeholder.com/150" alt="Image" /></td>
</tr>
<tr>
<td>Data compression</td>
<td>3 x 3 x 3</td>
<td></td>
<td><img src="https://via.placeholder.com/150" alt="Image" /></td>
</tr>
<tr>
<td>Integration time</td>
<td>2.3 ms</td>
<td></td>
<td><img src="https://via.placeholder.com/150" alt="Image" /></td>
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### Navigation

<table>
<thead>
<tr>
<th>Project Plan Line #</th>
<th>Bayern</th>
<th>Line Lbl</th>
</tr>
</thead>
<tbody>
<tr>
<td>Plan</td>
<td>132</td>
<td>A22</td>
</tr>
<tr>
<td>Line Lbl</td>
<td>184 GB</td>
<td>5 775 834 N</td>
</tr>
<tr>
<td></td>
<td>266 GB</td>
<td>3 820 m</td>
</tr>
<tr>
<td></td>
<td>2:19 h</td>
<td>Zone 3</td>
</tr>
<tr>
<td></td>
<td>602 371 E</td>
<td>3DD</td>
</tr>
<tr>
<td></td>
<td></td>
<td>7 Sats</td>
</tr>
<tr>
<td></td>
<td></td>
<td>G Dop 5.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H Dop 8.1</td>
</tr>
<tr>
<td>1° 14' 22.6&quot; N</td>
<td>52° 25' 15.3&quot; N</td>
<td>UTC 14:42:59</td>
</tr>
<tr>
<td>3° 27' 22.6&quot; E</td>
<td>8° 37' 22.6&quot; E</td>
<td></td>
</tr>
<tr>
<td>9° 29' 35&quot;</td>
<td>0° 29' 15&quot;</td>
<td></td>
</tr>
<tr>
<td>25.053 km</td>
<td>25.004 km</td>
<td></td>
</tr>
<tr>
<td>00h 29' 20&quot;</td>
<td>00h 00' 15&quot;</td>
<td></td>
</tr>
<tr>
<td>25.050 km</td>
<td>1.004 km</td>
<td></td>
</tr>
<tr>
<td>14' 000 ft</td>
<td>12' 530 ft</td>
<td></td>
</tr>
<tr>
<td>1' 470 ft</td>
<td>999.9 km</td>
<td></td>
</tr>
<tr>
<td>122.5 km</td>
<td>38.7°</td>
<td></td>
</tr>
</tbody>
</table>

- SOG 154 kts
Characteristics of the ADS40

Non pressurized
Up to 25,000 ft
7,620 m

GSD ½ ft / 15 cm: < 240 kn
GSD 1 ft / 30 cm: < 480 kn
GSD 2 ft / 60 cm: < 970 kn

Dynamic range of CCD
12 Bit

Radiometric resolution of spectral bands 8 Bit
Recording interval > 1.2ms

Data compression 2.5x - 25x

Non pressurized
Up to 25,000 ft
7,620 m

GSD ½ ft / 15 cm: < 240 kn
GSD 1 ft / 30 cm: < 480 kn
GSD 2 ft / 60 cm: < 970 kn

Dynamic range of CCD
12 Bit

Radiometric resolution of spectral bands 8 Bit
Recording interval > 1.2ms

Data compression 2.5x - 25x

Total
188 kg

< 35 A
< 980W/28VDC

ISO 7137
RTCA DO-160D

EN 50082-2
EN 55022
ISO 7137

FCC Part 15
FAR § 25.561
# Characteristics of the ADS40

<table>
<thead>
<tr>
<th>Bands</th>
<th>at $\lambda=50%$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Panchromatic, trapezoidal</td>
<td>465 nm - 680 nm</td>
</tr>
<tr>
<td>Spectral, rectangular</td>
<td></td>
</tr>
<tr>
<td>Blue</td>
<td>430 nm - 490 nm</td>
</tr>
<tr>
<td>Green</td>
<td>535 nm - 585 nm</td>
</tr>
<tr>
<td>Red</td>
<td>610 nm - 660 nm</td>
</tr>
<tr>
<td>NIR</td>
<td>835 nm - 885 nm</td>
</tr>
</tbody>
</table>

- **Inertial measurement system from APPLANIX**
  - IMU integrated in SH40
- **Sensor head SH40**
  - Fits PAV30 mount
- **GPS and POS integrated in CU40**
- **Control Unit CU40**
  - Shock mounted stand alone or 19" rack mountable
- **Operator Interface OI40**
  - Stand fits RC30 NAV-sight installation screws
Dimensions of airborne system components of ADS40

**Sensor head SH40**
Gyro-stabilized mount PAV30

**Control unit CU40**
Mass memory MM40

**Operator interface OI40**
Interface stand IS40

Measure units: **mm**

Flight direction

Fixing points on ground plates for mounting

Diameter of screw holes

© 2000 LH Systems, LLC
Cabling of airborne system components of ADS40
ADS40 - innovative technical highlights

- Automatic integration time control for perfect digital image quality
- Sealed Mass memory for reliable data storage
- Staggered CCD lines for high panchromatic resolution
- High data throughput
- Pressure sensitive touch screen for unambiguous operation
- Asymmetrically placed CCD lines for robust image matching
- Graphical MMI for easy operation
- Temperature controlled focal plate for high signal-to-noise ratio
- FCMS software for highly automated operation
- Trichroid for perfect RGB registration
- Wide angle optics for large swath width
- High resolution optics perfectly adapted to CCD
- Telecentric optics to maintain filter characteristics
- Sealed Mass memory for reliable data storage
- High data throughput
- Pressure sensitive touch screen for unambiguous operation
- Graphical MMI for easy operation
- FCMS software for highly automated operation
- Wide angle optics for large swath width
- Telecentric optics to maintain filter characteristics
Benefits of the ADS40 features

- Three sensors in one: black and white, color and false color images
- Wide area coverage for savings in flight lines and flying time
- Common lens and focal plate, combined with uniform sensor model, simplifies co-registration of multispectral information
- Perfect RGB co-registration through patented Trichroid device
- High quality DTMs derived from three-line stereo sensor data
- Reduced ground control due to tight integration of focal plate, IMU and GPS and the complete absence of film errors
- End-to-end digital flow line - no more photographic processing or scanning
The three-line principle, ground processing and the digital workflow
Digital data flow of ground processing

of ADS40 data

Level 0 - Raw data consisting of:
- Geometric raw images (TIFF and other formats)
- and processed orientation data

Level 1 - Rectified data consisting of:
- Fully corrected stereoviewable panchromatic images and fully corrected multispectral images

Level 2 - Geo-coded data consisting of:
- Panchromatic and multispectral orthophotos

Spectral channels simultaneously
Data flow of ground processing

Level 1

Orientation data ODF

Sensor calibration data

Level 1 generator

Fast Rectifier

Precision Level 1 rectifier

Orientation support data OSD

Image data level 0

Image data level 1

Coarse DTM

Meta data

Meta data

DPW

Stereo viewable
Data flow of ground processing

Triangulation

- Orientation data ODF
- Orientation support data OSD
- Image data level 1
- Meta data
- Sensor calibration data
- APM Automatic Point Matching
- Tie points
- ORIMA bundle adjustment
- Control points
- Precise orientation data ODF
- Self-calibration
- Meta data
- DPW
Software packages for data processing

LH Systems’ ADS level 0 generator and Applanix PosProc

LH Systems’ ADS level 1 generator

LH Systems’ SOCET SET® DPW ORIMA or 3rd party photogrammetric workstations with ADS sensor model
Link to 3rd party photogrammetric software packages

3rd party photogrammetric software packages
Link to remote sensing software packages

Level 0
- Image and positioning data
- GPS data
- Ground reference
- Orientation data
- Level 1 generator
- Positioning data
- Level 0 generator
- Meta data
- Image data level 0
- Orientation support data OSD
- Level 1 generator
- Fast Rectifier
- Precision Level 1 rectifier
- Sensor calibration data
- Image data level 1
- Meta data
- Coarse DTM

Level 1
- Orientation data
- Level 1 generator
- Sensor calibration data
- Orientation support data OSD
- Precision Level 1 rectifier
- Image data level 1
- Meta data
- Stereo viewable
- DPW
- ORIMA Bundle Adjustment
- Self calibration
- Tie-points
- Precise orientation data ODF
- Control points
- Meta data
- 3rd party remote sensing software packages
- Precise orientation data ODF
- APM Automatic Point Matching
- Tie-points
- Precise orientation data ODF

Triangulation
- Sensor calibration data
- Level 1 generator
- Fast Rectifier
- Precision Level 1 rectifier
- Image data level 1
- Meta data
- Stereo viewable
- DPW
- ORIMA Bundle Adjustment
- Self calibration
- Tie-points
- Precise orientation data ODF
- Control points
- Meta data
- 3rd party remote sensing software packages
Triangulation with the ADS40 using ORIMA

Ludger Hinsken
ADS40 specific aspects

- No direct relation between ground, image and orientation
  - Orientation parameters refer to Level 0 scan lines
  - Point measurements are performed in Level 1 images
  - Transformation between Level 1 and Level 0 using Orientation Support Data (OSD)
- One image has multiple orientation fixes
- Multiple scenes (forward, nadir, backward) share the same orientation fixes
- Accuracies of line and sample coordinates are different
- Tie point pattern depends on orientation fixes and scene length
Rectification of images from Level 0 to Level 1

Original Scene
(without gyro stabilization)

Rectified Scene
Orientation Fixes

- An orientation fix is the orientation of the sensor at a certain time.
- The distance between two fixes must be smaller than the short base.
- The time interval between two fixes depends on the gyro quality.
- The six orientation parameters for each fix are computed by the triangulation process; each fix is identified by the time.
- One image (scene) has multiple orientation fixes.
Orientation Fixes at a Fixed Interval

Forward scene
Nadir scene
Backward scene

Orientation fixes
Identical orientation for forward, nadir, backward
Points can be measured at any location
Each projected point falls in between two orientation fixes
The transformation ground to sensor is expressed as function of the two neighboring orientation fixes
The tie point pattern depends on the distance between orientation fixes and the length of the scene. In areas with sparse or no tie points, the orientation of GPS/IMU cannot be improved.
Ground to Sensor Transformation

- **Frame Sensor**

\[
\begin{bmatrix}
    x_{ij} \\
    y_{ij} \\
    c
\end{bmatrix} = \lambda_{ij} \mathbf{R}(\omega, \varphi, \kappa) \begin{bmatrix}
    X_i - X_j \\
    Y_i - Y_j \\
    Z_i - Z_j
\end{bmatrix}
\]

- **ADS40**

\[
x_{ij} = F_{ij} (X_i, Y_i, Z_i, X_k, Y_k, Z_k, \omega_k, \varphi_k, \kappa_k, X_{k+1}, Y_{k+1}, Z_{k+1}, \omega_{k+1}, \varphi_{k+1}, \kappa_{k+1})
\]

\[
y_{ij} = G_{ij} (X_i, Y_i, Z_i, X_k, Y_k, Z_k, \omega_k, \varphi_k, \kappa_k, X_{k+1}, Y_{k+1}, Z_{k+1}, \omega_{k+1}, \varphi_{k+1}, \kappa_{k+1})
\]

\[
X_j = c_j X_k + (1 - c_j) X_{k+1} + \delta X_j
\]

\[
c = F(\text{Distance between fixes}) = 0..1 \quad \delta X_j = F(\text{GPS, IMU})
\]

Published: 1991, F. Müller
Adjustment process

Orientation parameter

Interpolation correction

Orientation fixes

True orientation

Orientation for each line from GPS/IMU

Time
Precise orientation for each line in Level 0

GPS/IMU data is piecewise fitted to the orientation fixes
GPS/IMU observations

- 7 parameters to compensate different datum definitions

\[
\begin{bmatrix}
X_k \\
Y_k \\
Z_k
\end{bmatrix}
\begin{bmatrix}
X_0 \\
Y_0 \\
Z_0
\end{bmatrix}
+ \lambda \cdot R
\begin{bmatrix}
X_k \\
Y_k \\
Z_k
\end{bmatrix}
\]

- 3 rotation parameters to compensate misalignment

\[
R_{IMU_k} = R_{Misalign} R_{OriFix_k}
\]

\[
u_{IMU_k} = Q_{Misalign} u_{OriFix_k}
\]

\[
u = \begin{bmatrix} d \\ a \\ b \\ c \end{bmatrix}
\]

\[
Q_u = \begin{bmatrix}
d & -a & -b & -c \\
a & d & c & -b \\
b & -c & d & a \\
c & b & -a & d
\end{bmatrix}
\]
ORIMA Combined Bundle Adjustment

- Automatic computation of approximate values
- Combined adjustment for Frame and ADS40 images
- Super-large blocks are handled extremely fast
- Flexible handling of airborne-GPS and IMU attitude data
  - GPS systematic parameter capability (time dependent and independent)
  - Calibration of sensor-to-IMU axes misalignment
- Variance component estimation
  - Determines correct weighting relationship between observables
- Automatic blunder detection and elimination
  - Accounts for geometry of the block
- Self-calibration up to 21 parameters
Highly interactive graphical working environment

- Selective display of:
  - Point IDs
  - Residual vectors
  - Error ellipses
  - Reliability
  - GPS parameter effects
  - Numerical values
  - Strip connections
  - Ground coverage
  - And much more!

- Interactive analysis
  - Remeasuring points
  - Adding points
  - Disregarding points
New ORIMA versions

- ORIMA for Frame and ADS40
- ORIMA for ADS40 only
- Fully integrated into SOCET SET
  - Support for the multi-line sensor geometry
  - Automatic and interactive point measurement
  - Computation of precise orientation parameters for each sensor line
Advantages and benefits of ORIMA for ADS40

- Same graphical user interface as known from Frame images
- Frame and ADS40 images can be mixed in one project
- Fully integrated into SOCET SET®
- Comprehensive analysis tools based on statistical methods
- Continuously maintained and improved
- Supported worldwide by highly skilled support engineers
Airborne digital sensor