On-Ground Verification of VIBANASS
(Vision Based Navigation Sensor System):
Capabilities and Results

12th Symposium on Advanced Space Technologies in Robotics
and Automation
ESA/ESTEC / Noordwijk / 17.05.2013
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Introduction

- VIBANASS is an optical navigation sensor system designed for rendezvous and docking applications

VIBANASS comprises:

- Two Camera Systems (CS), each with
  - Far Range Camera (3km to 75m)
  - Mid Range Camera (500m to 4.5m)
  - Close Range Camera (5m to 0.7m)
- Laser-based Target Illumination (TIS) System to enhance the natural illumination in close range
- Ground Operation System (GOS) including image processing algorithm for target tracking
- The two Camera Systems can be used as a stereo camera system in close range
- Possible applications include the Orbital Live Extension Vehicle (OLEV)
- Successfully tested under realistic illumination conditions at the new European Proximity Operations Simulator (EPOS) at DLR/GSOC in Oberpfaffenhofen
Agenda

- Description of VIBANASS
  - Camera System
  - Target Illumination System
  - Ground Operation System

- Test Setup

- Test Results
  - General Test Results
  - Evaluation of Image Quality
  - Evaluation of Tracking Algorithm

- Summary
VIBANASS Camera System

Core functions:

- Image size up to 1024x1024 pixel
- Image acquisition rate: max 10Hz
- Lossy and lossless JPEG compression
- Configurable image size
- Redundant SpaceWire interface Encoder/Decoder
- Individual control of each camera head
- Synchronization for stereo camera and with TIS
- Simultaneous operation of 2 camera heads
- Optional Image Processing Module (internal Add-on Module for image pre-processing functions)
- Power consumption: 28 V / 5 W
- 4.8 kg for GEO application and 3.7 kg for LEO
- Size of CS: 250.5mm x 236.5mm x 215.1mm

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On-Ground Verification of VIBANASS: Capabilities and Results
VIBANASS Target Illumination System

General requirements
- Illumination with at least 10% of the irradiance of natural sunlight within a bandwidth of 20nm
- For reference mission:
  - Field of view: 42° x 42°
  - Distance: up to 5m
  - Required optical power: 32 Watt

Modular approach
- TIS Power Supply Unit and 2 TIS Laser Diode Arrays
- Size of TIS-PSU: 169 mm x 106 mm x 40 mm
- Size of TIS-LDA: 70mm x 76mm x 20mm
- Mass: 2.05 kg (incl. 2 LDAs) for GEO, 1.65 kg for LEO
- Power consumption: 28 V / 15 W @ 16W optical power and 10% duty cycle
- Successfully tested with a TID of 235 KRad(Si) and with 3.1E11 protons/cm² @ 30MeV
VIBANASS Ground Operation System

Features of VIBANASS GOS:

- The GOS connects to:
  - Two Camera Systems (CS)
  - One Target Illumination System (TIS)

- GOS emulates OBC/ICU Interfaces against CS and TIS

- GOS implements a GUI for:
  - Display of telemetry
  - Generation and transmission of telecommands
  - Recording of camera images including playback functionality

- GOS comprises power supply for CSs and TIS

- Distribution of system time via SpaceWire (Camera System) and local network (GOS)
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Test Setup

Test articles and test equipment
- Left Camera System: CAM-CR and CAM-MR
- Right Camera System: CAM-CR
- Target Illumination System:
  - Power Supply Unit
  - 2x Laser Diode Array
- Ground Operation System
  - VIPU with image processing / tracking algorithm
- Mockup of target satellite

53 Test cases
- 4 different positions of the sun simulator
- 5 different trajectories (nominal and non-nominal)
- Different relations between the brightness of TIS and sun: 
  TIS/Sun = 0%, 5%, 10%, 20%, no sun

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Test Setup

CS-A (Right Camera)  LDA-BB

CAM-CR

Capture-Tool

CS-B (Left Camera)

CAM-MR

GOS (OBC)

TIS-PSU

LDA-DM
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Test Results – Video

Camera002
Speed: 6x

Mid-Range Camera
General Test Results

Camera System
- Internal Power Supply, digital electronic, CAM-CR and CAM-MR were operated with different acquisition rates and different downlink rates
- Operating temperature within expected range
- Synchronization between CS-A and CS-B: accuracy < 1ms

Target Illumination System
- TIS-PSU and 2 TIS-LDAs were operated in synchronization with the Camera System
- Power consumption and operating temperature within expected range
- Total measured optical power: 17.1W, Irrdiance @ 5m: 1.64 W/m²
- Homogeneity of illumination pattern > 95%
General Test Results

Optical tests
- Have been conducted due to uncertainties during the straylight analysis
- Impact of the baffles in the image quality has been investigated using an increasing amount of straylight
  - No impact on SNR
  - Increased contrast when using baffles at a high amount of straylight
General Test Results

Delay
- Measured between image acquisition at the Camera System, transmission of the full image to the GOS and after Image processing
- Depending on image size and compression setting
- Synchronization with common GPS time

<table>
<thead>
<tr>
<th>Image Compression</th>
<th>CS to VIPU</th>
<th>Image Processing</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lossless</td>
<td>350 ms</td>
<td>130 ms</td>
<td>480 ms</td>
</tr>
<tr>
<td>Low Compression</td>
<td>75 ms</td>
<td>130 ms</td>
<td>205 ms</td>
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<tr>
<td>Medium Compression</td>
<td>35 ms</td>
<td>130 ms</td>
<td>165 ms</td>
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<tr>
<td>High Compression</td>
<td>20 ms</td>
<td>130 ms</td>
<td>150 ms</td>
</tr>
</tbody>
</table>
Evaluation of Image Quality

**SNR**

- CAM-CR: strong dependency on distance and illumination conditions
- CAM-MR: weak dependency on distance and illumination conditions
- Fall-off at 2m: Occlusions and shadows induced by the target satellite increase straylight
Evaluation of Image Quality

Blur
- Dependency on contrast, no dependency on illumination conditions

Contrast
- No dependency on contrast, weak dependency on illumination conditions
- Fall-off at 2m: Occlusions and shadows induced by the target satellite increase straylight

Dependency of illumination conditions on image quality
- CAM-MR: Weak dependency
- CAM-CR: Strong dependency
- Strongest fall-off at P4

![Graph showing the relationship between distance and SNR (Signal-to-Noise Ratio)]
Evaluation of Image Quality

Impact of position of sun simulator:
- CAM-MR
- without TIS

P1

P4

<table>
<thead>
<tr>
<th>Distance</th>
<th>Image 1</th>
<th>Image 2</th>
<th>Image 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 m</td>
<td><img src="image1.png" alt="Image" /></td>
<td><img src="image2.png" alt="Image" /></td>
<td><img src="image3.png" alt="Image" /></td>
</tr>
<tr>
<td>12.5 m</td>
<td><img src="image4.png" alt="Image" /></td>
<td><img src="image5.png" alt="Image" /></td>
<td><img src="image6.png" alt="Image" /></td>
</tr>
<tr>
<td>5 m</td>
<td><img src="image7.png" alt="Image" /></td>
<td><img src="image8.png" alt="Image" /></td>
<td><img src="image9.png" alt="Image" /></td>
</tr>
</tbody>
</table>
Evaluation of Image Quality

Impact of position of sun simulator:
- CAM-CR
- with TIS (10%)

P1

P4

5 m

3.5 m

2 m
Evaluation of Image Quality

Impact of image compression

- Compression levels (Stereo image pair, resolution of 1024x1024px, 8bit, 1 image per second)
  - Lossless
  - Low compression (4MBit channel), typical bandwidth for LEO application
  - Medium compression (2MBit channel)
  - High compression (0.4MBit channel), typical bandwidth for S-Band link in GEO application
- Better SNR for compressed images due to noise reduction during compression
Evaluation of Tracking Algorithm

Goals and approach

- Identify and quantify the impact of illumination conditions on the accuracy of the tracking algorithm
- Measurement of the relative error in x-, y- and z-direction
- Orientation of the target is assumed to be known
- GPS-Signal for time-synchronization between VIBANASS und EPOS
Evaluation of Tracking Algorithm

Stereo-Tracking (CAM-CR)
- Strong dependency on the used trajectory
  - Nominal approach: N1
  - Sinusoidal rotations at N2 and N3
  - Speed was increased by a factor of 5
- Strong dependency on the illumination conditions

Mono-Tracking (CAM-MR)
- No dependency on illumination conditions could be identified
Evaluation of Tracking Algorithm

Dependency on the illumination conditions

- TIS significantly increases the accuracy
- Presence of TIS more important than brightness
- Position of sun simulator has a smaller impact than brightness of the TIS
Evaluation of Tracking Algorithm

Impact of image compression

- Compression levels: lossless, low (4MBit channel), medium (2MBit channel) and high (0.4MBit channel)
- No impact of image compression could be measured, even for a low bandwidth of 0.4 MBit
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EPOS Tests – Summary

General tests with the Camera System and the Target Illumination System

- Delay: 130ms for image processing, 20ms … 250ms for image acquisition and transmission
- Optical requirements (e.g. SNR or field of view) have been fulfilled

Evaluation of the VIBANASS EPOS-Tests

- The impact of illumination conditions on the image quality was investigated
- Image compression has an impact on SNR but no impact on the accuracy of the tracking algorithm could be measured
- Tracking fulfills the required accuracy under good conditions during a nominal approach
- A strong relation between the tracking algorithms and the illumination conditions and the selected trajectory could be found in close range
- The Target Illumination System significantly increases the accuracy of the tracking algorithm

VIBANASS is a Kayser-Threde development programme under co-funding by DLR (Förderkennzeichen 50RA1001), the German Space Agency and in cooperation with DLR-RM (DLR Institute for Mechatronics and Robotics) and DLR-RB (EPOS). vH&S (von Hörner und Sulger) is subcontractor.