OPTICAL NAVIGATION FOR EXPLORATION MISSIONS

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Background
Our activities in optical navigation

• Since 2010 ongoing DLR internal project
  • ATON – Autonomous Terrain based Optical Navigation
  • Contributions from several DLR centers

• DLR research goals
  • Development of technologies for autonomous optical navigation of exploration vehicles (planetary landing, asteroid landing, hovering, …)
  • Verification of algorithms, sensors and systems in ground-based test facilities

• Further Contributions from several externally funded projects
Overview

DLR activities in terms of asteroid navigation

- Simulation of dynamics and sensor data
- Methods for extracting sensor data from images
  - crater navigation
  - star tracking in images
  - feature tracking
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- Filtering, data fusion and state estimation
- Design and building of sensors and GNC systems

Navigation system for sounding rockets (SHEFEX-2)

Miniaturized GNC system for exploration missions (SINPLEX)
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- Test labs for verification
Crater navigation method overview

- Sensor in lunar orbit taking images
Crater navigation method
Overview

- Sensor in lunar orbit taking images
- Input: image of the lunar surface
- Processing image data and on-board data
  - Detecting craters, matching craters with on-board database
- Output: position and attitude of space craft in lunar orbit
- All necessary information on-board the sensor
- Works autonomously

\[
q = \begin{pmatrix} q_0 \\ q_1 \\ q_2 \\ q_3 \end{pmatrix}
\]

\[
x = \begin{pmatrix} x_0 \\ x_1 \\ x_2 \end{pmatrix}
\]
Crater navigation method
Characterization

- Characterization of the algorithm software-in-the-loop
- Question: How successful is the crater matching under different conditions?
  - varying camera elevation and azimuth
  - varying sun elevation and azimuth
- Processing of \( \approx 130000 \) images
- DEM for rendering based on Kaguya data
Crater navigation method

Characterization

- Characterization images
  - 1 MPixel
  - FOV ≈ 66°
Crater navigation method
Characterization results

- Result:
  - Crater navigation works over broad range of viewing and lighting conditions
Crater navigation method
Characterization results

• Result:
  • Crater navigation works over broad range of lighting and viewing conditions
Crater navigation method
Application test in TRON

- Test of navigation function in Descent orbit
Crater navigation method
Free-hand demo
Crater navigation method
Application test on helicopter

- Test of hybridization of IMU and Crater Navigation with real data
- Test setup
  - IMU and camera on helicopter
  - Planes as crater targets
  - Crater catalogue in GPS coordinates

Helicopter setup

Crater setup
Crater navigation method
Application test on helicopter

- Test of hybridization of IMU and Crater Navigation with real data
- Successful data fusion in Kalman Filter
Crater navigation method
Application to asteroid scenario

- Eros inertial hovering
- Simulated images
Crater navigation method
Application to asteroid scenario

- Eros approach
- Hardware-in-the-Loop in TRON

Model of Eros in TRON, scale 1:34000
Crater navigation method
Crater map generation

• If a crater catalogue is missing we can generate it
• Application of crater navigation to computer generated images
• Result: map which contains 3D position and radius of each mapped crater in moon fixed coordinates
Crater navigation method
Crater map generation

Automatically Mapped Craters (750; in Green)
Crater navigation method

Conclusion

• Crater Navigation approach provides:
  • absolute navigation solution (with crater catalogue)
    • Identified craters (for predictor corrector)
    • lost-in-space position solution
  • Unknown landmarks as stable drift-free features (w/o catalogue)
    • For feature tracking
    • For SLAM (builds catalogue)

• Robustness
  • no state knowledge needed
  • Broad range of viewing angles: 30° - Nadir (ca. 80% success)
  • Broad range of local sun elevation: 5° - 50° (ca. 80% success)

• Software can be applied on available space proven hardware
• Current work: share the work between normal processor and FPGA
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- Navigation system for sounding rockets (SHEFEX-2)
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Small Integrated Navigator for PLanetary EXploration
SINPLEX

- Miniaturized optical navigation system for Moon/asteroid landing, rendezvous/capture
- Integrates IMU, star tracker, laser altimeter and navigation camera
- Total target mass < 6kg (redundant system)
- Mass reduction through functional integration and miniaturized electronics
- Uses sensor data fusion to improve navigation performance and compensate for loss of sensor performance due to miniaturization
- Image processing includes:
  - Feature tracking for terrain relative EKF-SLAM
  - Crater navigation
  - Object relative navigation (spherical objects, e.g. sample container, planet)
SINPLEX Breadboard Testing in TRON
asteroid landing
SINPLEX Breadboard Testing in TRON Asteroid approach

• Feature tracking
SINPLEX Breadboard Status

- Hardware fully integrated
- Specifications:
  - 3.1kg
  - 17 x 21 x 20cm
  - 16.3W
- Differences to FM:
  - No redundant components
  - COTS laser driver
- Breadboard tests completed
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TRON - Testbed for Robotic Optical Navigation

- TRON provides environment for
  - developing algorithms
  - qualifying hardware up to TRL 6
TRON - Testbed for Robotic Optical Navigation

- Design allows various mission scenarios
- High precision ground truth
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TENSOR – mobile testbed

- TENSOR - TEsting Navigation Systems On airfield Runway
  - complementary environment for true-scale tests
  - Longer range, higher speed

▲ Test of Flash LIDAR sensor
TENSOR – mobile testbed

- IMU / RTK-GPS based ground truth
- Design allows various kinds of targets
- range
We have the expertise for supporting the navigation of asteroid missions
We can contribute in many ways
• Methods and Sensors
• GNC systems fusing data to optimum solution
• Flexible testbeds for maturing technologies up to TRL 6