Fusion
Absolute Vision-based Localization
Visual Odometry
for
Spacecraft
Absolute Navigation

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T. Voirin (2), M. Drieux (3), C. Bourdarias (3)
Context

→ Visual Odometry is **good** for safe landing but **not enough** for precise landing.

**MER-A DIMES Result**

Credit: JPL/NASA
Where is our work?
Our idea

Does it Work?

Possible solution

Is it flight ready?

Possible solution

Possible solution
Visual Odometry Concept
Visual Odometry
Visual Odometry

\[ p(t) = \int v(t) \, dt \]

\[ \hat{v}_{1,2}, \hat{\theta}_{1,2} \]

with

\[ \hat{v}_{1,2} = v_{1,2} + \hat{\varphi}_{1,2} \]
Karma Flight Demonstration
(LAAS-CNRS 1997-2002)

Karma Test Place
Karma Flight Demonstration
(LAAS-CNRS 1997-2002)
Visual odometry performance with Dala

Visual Odometry

GPS

XY plane

optical odometry
odometry
gps
Position estimation with V.O for lunar lander
Absolute Navigation

- LIDAR/Altimeter
  - VISINAV
  - Mourikis et al. 09

- Camera
  - APLNAV
  - Adams et al. 08

- GNSS
  - LANDSTEL
  - Pham et al. 09
Absolute Vision Based Localization
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LANDSTEL
Absolute Vision Based Localization

LANDSTEL
Absolute Vision Based Localization

LANDSTEL
Absolute Vision Based Localization

LANDSTEL – Shape Context - OCR
Absolute Vision Based Localization

Why LANDSTEL?
Absolute Vision Based Localization

Why LANDSTEL?
Absolute Vision Based Localization

Why LANDSTEL?
Absolute Vision Based Localization

Why LANDSTEL?
Absolute Vision Based Localization

Why LANDSTEL?
Absolute Vision Based Localization
Other examples
Other examples
Other examples
Experiment of Landstel with Moon Coasting Phase

<table>
<thead>
<tr>
<th>Start Point</th>
<th>Altitude</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>100km</td>
<td>43s</td>
</tr>
<tr>
<td>B</td>
<td>58km</td>
<td>43s</td>
</tr>
<tr>
<td>C</td>
<td>29km</td>
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<table>
<thead>
<tr>
<th>Velocity Error</th>
<th>Value (3σ)</th>
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<tbody>
<tr>
<td>X</td>
<td>1m/s</td>
</tr>
<tr>
<td>Y</td>
<td>1m/s</td>
</tr>
<tr>
<td>Z (alt)</td>
<td>1.5m/s</td>
</tr>
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Experimental Surface

320 km 320 km
Video Demo (vid1)
Outline

• Visual Odometry (VO)
• Absolute Vision-Based Localization (AVL)
• Fusion of AVL and VO principles
• Fusion of AVL and VO
• Experimental result(s)
• Conclusion
# Lander Sensors

<table>
<thead>
<tr>
<th></th>
<th>Landstel</th>
<th>Visual Odometry</th>
</tr>
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<tbody>
<tr>
<td><strong>Orientation</strong></td>
<td>Not implemented</td>
<td>3D(Ψ,Θ,Φ) Highly precise</td>
</tr>
<tr>
<td><strong>Position</strong></td>
<td>3D(x,y,z) Global</td>
<td>Velocity Local High</td>
</tr>
<tr>
<td></td>
<td>Low precision</td>
<td>precision</td>
</tr>
<tr>
<td><strong>By Product</strong></td>
<td>Matched Points</td>
<td>Tracked Points</td>
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</table>

**Complementary Information**
AVL & VO fusion
State of the art VISINAV

Ultra Tight integration of VO and ALV

Mourikis et al. 09
But ... not feasible with a black box VO

LANDSTEL

Initial position uncertainty → Processing → v, θ

X, y, alt (abs)

IMU-Aided GPS like
VO∞AVL

- Features Points
  - Robustification
  - Fault Detection
- Position, Velocity
  - Position Refinement
  - Focalization

AVL-VO only
GPS-IMU inspired
Point 1

AVL Robustification
Point2

Vision Based Fault Detection
Vision Based Fault Detection
Prediction Function

\[ U = K[R^T, -R^T]M \]
Back Projection

DEM Model
Vision Based Fault Detection
Prediction vs. Observation

Blue Points: AVL Matched Points

Red Points: Prediction Points
Green Points: Observation Points
Point3

Position Refinement

Global State

Visual Odometry

LANDSTEL

Initial position uncertainty

Processing

Global State

\[ \delta \hat{p}_k, \hat{P}_k \]

\[ \{ \hat{p}_{k-1}^{\text{Global}} \} \hat{P}_{k-1} \]

\[ \{ \hat{p}_{k|k-1}^{\text{VO}} \} \]

\[ \{ \hat{p}_{k|k-1}^{\text{Local}} \} \]

\[ \delta \hat{p}_{k|k-1} \]

Kalman filter
Point3

Position Refinement

\[ t_5 \]

\[ \text{INS}_{t_6} \]

\[ \text{LS}_{t_6} \]

Surface
Point 4

AVL Acceleration

\[ \hat{P}_2 = \tilde{P}_1 + \hat{v}_{1,2} \]
Outline

• Absolute Vision-Based Localization (AVL)
• Visual Odometry (VO)
• Fusion of AVL and VO principles
• Fusion of AVL and VO
• Experimental result(s)
• Conclusion
Comparison Result (vid2) with standalone Landstel
Comparison Result
with standalone Landstel (#IP)
Moon Coasting Phase

Video Pictures Demo

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Coasting Phase
(Point A)
Coasting Phase
(Point B)
Coasting Phase
(Point C)
Coasting Phase
Position Estimation Error
Mars Descent
**Conclusion (1)**

VIBAN is not precise in comparison with others

<table>
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<tr>
<th>System</th>
<th>Precision</th>
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<tr>
<td>VISINAV (Mars)</td>
<td>6.4 m error</td>
</tr>
<tr>
<td>VIBAN (Mars)</td>
<td>10 m error (best), $N(24,50)$</td>
</tr>
<tr>
<td>APLNAV (Moon) (100 km alt)</td>
<td>350 m error</td>
</tr>
<tr>
<td>VIBAN (Moon) (100 km alt)</td>
<td>1.5 – 2 km error</td>
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### Performance Values

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<th>Values</th>
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<td>Illumination (geo/descent)</td>
<td>± 15 elevation, ± 180 azimuth (impact on position precision)</td>
</tr>
<tr>
<td>Robust to</td>
<td>Scene appearance variance Geo Image “band-aiding” …</td>
</tr>
<tr>
<td>Memory</td>
<td>~200 KB / 2048 x 2048p image (including DEM)</td>
</tr>
<tr>
<td>Hardware</td>
<td>5 Hz with 2GHz CPU (standalone)</td>
</tr>
<tr>
<td>Moon coasting at 29 km without altimeter</td>
<td>350m (magnitude) precision</td>
</tr>
<tr>
<td>Mars descent at touch down (32 km dispersion at parachute)</td>
<td>N(50,50)m (magnitude) for most of the cases (obsolete)</td>
</tr>
<tr>
<td>Earth Image (artificial &amp; natural)</td>
<td>Usable</td>
</tr>
</tbody>
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Conclusion (3)

- **VO∞AVL**
  - **Features Points**
    - 1. Robustification
    - 2. Fault Detection
  - **Position, Velocity**
    - 3. Position Refinement
    - 4. Focalization
What will we do next?
continue pushing the arrow...

Does it Work?

Possible solution

Is it flight ready?

Our idea

Possible solution

Possible solution

continue pushing the arrow…
Thanks for your attention!
Interest /Corner/Feature Point Illustration

Credit: Wikipedia