SLAM from Air

An application of SLAM with aerial stereo imagery (only)

Context: exploration robotics
Air/ground cooperative robotics

Application in natural, unstructured environments:
Scientific (planetary) exploration, Mapping, Surveillance, Environment monitoring, Intervention...

Autonomous blimp project at LAAS:
Topics considered:
• Airship control
• Air/ground mapping and exploration
• Air/ground cooperation
Airobot and Landrobot cooperation
Outline

• Digital elevation maps

• Algorithms
  StereoVision
  Interest points matching
  Motion estimation
  DEM update

• SLADEM: overview
  Prediction error
  Observation error

• Simulations and first results

Digital Elevation Maps

DEM: \( z = f(x, y) \) on a regular Cartesian grid

Steps of the DEM building process:

• Init:
  3D Data acquisition (stereovision)
  DEM update (elevations and luminance)

• Loop:
  Motion
  3D data acquisition
  Motion estimation
  Position refinement: SLADEM
  DEM update (elevations and luminance)
Mapping with stereovision: principle

Set of non-registered aerial stereo frames

↓

High resolution digital elevation map

Algorithms:
• Stereovision
• Motion estimation (interest point matching)
• Position refinement (SLAM approach)
• DEM update

Stereovision

Classical pixel-based correlation algorithm
Errors in stereovision

• Errors on the disparity estimates

  empirical study: \( \sigma_d = f(c) \)

• Errors on the 3D coordinates \( x = \frac{\alpha}{d} \) \( \Rightarrow \) \( \sigma_x = \frac{\sigma_d}{\alpha} x^2 \)

Online estimation of the errors

Maximal errors:
- 0.4 m baseline: \( \sigma_x \leq 10^{-3} x^2 \)
- 1.2 m baseline: \( \sigma_x \leq 3 \times 10^{-4} x^2 \)

Motion estimation: principle

1. Stereovision
2. Pixel selection (interest points)
3. No prediction
4. Interest points matching
5. Motion estimation
Interest point matching algorithm

1. Interest point detection (Harris)

2. Hypotheses generation

3. Local grouping, hypotheses confirmation

4. Affine transf. estimate, propagation

5. Outlier rejection (epipolar geometry)

IPM algorithm: results
DEM

- Sensor accuracy and viewpoint influence on a regular grid projection

![Diagram](image)

DEM update

Simulation results on a 2D profile:

One acquisition

Fusion of 36 acquisitions

Update strategy: Bayes, Dempster-Shafer

Current solution: a cell is represented by \( (Z, s, c) \):
- Elevation accuracy derived from the points accuracy
- Confidence derived from the points covered surface
A few % translation error

DEM from aerial stereo images (just motion prediction, no SLAM)

1 pixel: 5 cm

DEM from aerial stereo images (just motion prediction, no SLAM)

1 pixel: 5 cm

A few % translation error
DEM built with visual motion estimation only

A few % Translation error

Position refinement: SLAM approach

1. Interest points detection
2. Interest points matching
3. Landmark selection (blue pixels)
4. Prediction (using non-landmark pixels)
5. Observation (landmarks pixels) : filter update
Filter setup

- **State**: robot (stereo rig) position (6 parameters) + landmark positions (3 parameters each)

\[
S = [ S_r, S_l ]; \quad S_r = [ \Theta, \Phi, \Psi, P_x, P_y, P_z ]
\]

\[
S_l = [ X_1, X_2, X_3, \cdots ]; \quad X_i = [ x, y, z ]
\]

- **Prediction error**: on-line statistics derived from the position estimated with \( n \) subsets of the \( m \) matched points

(typically: \( m > 200, n = 50; \) std deviations ~ 0.1º and 0.01m for 1m displacements)

Filter setup (2)

- **Observation error**:
  - New landmark: stereo error model
  - Re-perceived landmark: stereo error + matching error

Matching error derived from the neighbor points  

- **Landmark selection among all the interest points**:
  - Good accuracy of the coordinates (stereo error model)
  - Located on rather smooth areas (matching errors)
  - Well matched in several images
  - Rather uniformly spaced
Filter results

- Decreases the accumulation of errors
- When re-perceiving an area: possibility to observe the state with non-selected interest points
- After a loop: landmarks position update ➔ blimp position updates and DEM re-computation

DEM

With motion estimation only

With Kalman
Conclusions

Work in progress.

- Better qualification of errors required
- Better DEM update functions (deal with moving objects)
- Lots of parameters to tune/evaluate
- Other SLAM techniques
- Bundle adjustment