Application of Visual-Inertial SLAM for 3D Mapping of Underground Environments

Robotics and Intelligent Systems Unit
António João Ferreira
José Miguel Almeida
Eduardo Pereira da Silva

IROS 2012 - 4th Workshop on Planning, Perception and Navigation for Intelligent Vehicles | 7 October 2012 | Vilamoura, Portugal
Goals

- Accurate modelling of underground galleries
- Fast data acquisition (mobile vehicle)
- All sensors carried on board
- Galleries with uniform geometry
Mine Mapping

Environment: Mines
Sensors: Laser Range Finders
Localization Technique: Scan Matching

Scan Matching

Laser scans from the interior of a road tunnel.

Scan 1

Scan 2
Problem

Autonomous localization in a challenging environment:

- Monotonous Geometry – Scan matching techniques fail
- No GPS
- Forward motion
- Lighting variations
High Level Architecture

Data Acquisition → Images → Autonomous Localization

Inertial measurements

3D Modelling

Tunnel cross-sections (LRF scans) and Texture → Localization estimate

3D model
Data Acquisition

Data acquisition platform:

- Inertial Navigation System (iMAR iNAV-FMS-E)
- Low cost inertial sensor (MicroStrain 3DM-GX1)
- 2 Laser Range Finder (SICK LMS)
- 2 CCD cameras (JAI CB-080GE)
- Mini-ITX board (Intel® Core™ 2 Quad 2.53 GHz)
Autonomous Localization

Data Acquisition

Images

3D Modelling

Images

Localization estimate

3D model

Inertial measurements

Tunnel cross-sections (LRF scans) and Texture

Inertial measurements

3D model

Texture Images

Inertial measurements

3D model
Autonomous Localization

Dataset

Images → SIFT features extraction → SIFT features and descriptors → Feature matching

Inertial measurements → Feature matches

**EKF SLAM**

Visual map (Inverse Depth Parametrization)

Inertial based prediction

Localization
Undelayed landmark initialization

- Inverse depth represented by a Gaussian.
- Landmarks defined by 6 parameters:

\[ y_i = [x_i^n, y_i^n, z_i^n, \theta_i, \phi_i, \rho_i]^T \]

Scale Ambiguity

Monocular cameras:

- Relative orientation observations
- Do not provide metric measurements

Consequence:

- Map and motion defined under unknown scale
Inertial Prediction

Inertial based EKF prediction

Motion model – Inertial mechanization in the Local Level frame

\[
\begin{bmatrix}
    x^n(k) \\
    \Theta^n(k) \\
    v^n(k)
\end{bmatrix}
= \begin{bmatrix}
    x^n(k-1) + v^n(k) \Delta t \\
    \Theta^n(k-1) + E^n_b w^b(k) \Delta t \\
    v^n(k-1) + [C^n_b a^b(k) - g^n] \Delta t
\end{bmatrix}
\]
3D Modelling

Data Acquisition

Images
Inertial measurements

Autonomous Localization

3D Modelling

Tunnel cross-sections (LRF scans) and Texture

Localization estimate

3D model

Inertial measurements
3D Modelling

1) Conversion to Cartesian coordinates

2) Transformation of each scan to the navigation frame

\[ P^n = C^n_b \left( C^n_c \left( P^l - (x^l)_c \right) - (x_c)^b \right) - (x_b)^n \]

3) Mesh generation using the Ball Pivoting Algorithm

4) Noise reduction and texture mapping
Results
Results – Data Acquisition

Data acquisition experiment:

- Road tunnel (Vilar de Luz – Maia)
- Approximately 140 meters long
- Maximum speed of 35 Km/h
Results - Localization

SLAM
(Inertial and Visual Measurements)

Localization precision

Advantage of inertial and visual data fusion

Ground Truth

MonoSLAM

Inertial Mechanization
Results - Localization

Trajectories

- Inertial + MonoSLAM
- MonoSLAM
- Ground Truth
- Inertial Mechanization
Results - Localization

Position errors

Final errors:
- 11.7m
- 8.7m
- 0.95m
3D Model – Point Cloud

Model with 167380 points
Ball Pivoting Algorithm (Point Cloud -> Triangular Mesh)
Triangular mesh after Laplacian filtering
Texture mapping
Future Work

- Estimate the inertial sensor errors
- Implement stereo vision
- Improve data association to allow loop closure
- Preform tests in longer galleries
Thank you!
Gyros Drift = 0.75°/h
Acc. Bias = 1.5 mg
Scan Matching

Compute sensor displacement \((R, t)\) from two consecutive scans by iteration:

- Point matching
- Point-to-point distance minimization
- Apply computed transformation to one scan