Edge Landmarks in Monocular SLAM

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Simultaneous Localisation And Mapping
The One-Slide Version

Mobile Sensor

Environment

foo

baz

bar

fred

Observations

Where am I?

What is the structure of my environment?
Monocular SLAM with Points

Calibrated Camera (6DoF)

Locally-planar textured 3D Points

Image locations (u,v)

What is my pose?

What do I know about 3D locations given 2D observations?
Monocular SLAM with Edges

What is an edge in the world?

What is an edge in the image?

How should we \{select, parametrise, observe, estimate\} edges?
Monocular SLAM with Edges

**Required**
- Definition
- Representation
- Observation
- Selection
- Initialisation

**Why Bother?**
- Build a richer map
- Depend less on textured environment
- Benefit from more information
Monocular SLAM with Edges

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Contributions
Define edgelets; show how to represent, observe, select, and initialise them
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**Contributions**
Define *edgelets*; show how to represent, observe, select, and initialise them

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Definition

edgelet:
A locally-straight piece of 1D structure that appears as an intensity change.

An edgelet...

• might be part of a longer straight segment
• might be part of a longer, slowly curving or piecewise-straight segment
• appears as a short straight edge in images
• is more than an edgel
Representation

An edgelet describes the derivative of the 3D edge $L(t)$ at a chosen point:

$$\vec{d} \equiv \frac{\partial L(t)}{\partial t}(t_0)$$

Some boundary curve $L(t)$ in $\mathbb{R}^3$
<table>
<thead>
<tr>
<th><strong>Point</strong></th>
<th><strong>Edgelet</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>Locally planar structure</td>
<td>Locally linear structure</td>
</tr>
<tr>
<td>3D state: point</td>
<td>5D state: point, direction</td>
</tr>
<tr>
<td>2D texture</td>
<td>1D intensity change</td>
</tr>
<tr>
<td>2D observations</td>
<td>2D observations</td>
</tr>
<tr>
<td>(image point)</td>
<td>(image line)</td>
</tr>
<tr>
<td>Distinctive, rich descriptor</td>
<td>1-bit descriptor</td>
</tr>
</tbody>
</table>
Observation

Project uncertainty into image, and search for straight segments in a gated region.
Observation

1. Compute search region and direction
Observation

1. Compute search region and direction

2. Find edgels in region
Observation

1. Compute search region and direction
2. Find edgels in region
3. Group edgels into straight segments
Observation

1. Compute search region and direction
2. Find edgels in region
3. Group edgels into straight segments

Multiple possible matches
Observation

1. Compute search region and direction
2. Find edgels in region
3. Group edgels into straight segments

Collect all observations each frame and find the maximum-likelihood data association using MLESAC
Selection: Finding new Edgelets

Data association is not straightforward for edgelets. How can we make our job easier?

We want short edge segments that are

- straight

- separated from other segments of similar orientation
Selection: Finding new Edgelets

1. Find Canny-like edgels (no linking)

2. Divide the edgels with a grid.
   For each cell:
   a) Find the dominant gradient direction \( d \)
   b) Find edgels in agreement with \( d \)
   c) Threshold on variance of position in direction \( d \)
Initialisation of New Edgelets

• Highly non-Gaussian distributions in Cartesian coordinates

\[
\begin{pmatrix}
  x \\
  y \\
  z \\
\end{pmatrix}
\begin{pmatrix}
  dx \\
  dy \\
  dz \\
\end{pmatrix}
\]
Initialisation of New Edgelets

• Highly non-Gaussian distributions in Cartesian coordinates

• Inverse-depth coordinates make the observation model nearly linear...

\[
\begin{pmatrix}
  x \\
  y \\
  z
\end{pmatrix}
\quad
\begin{pmatrix}
  dx \\
  dy \\
  dz
\end{pmatrix}
\]

\[
\begin{pmatrix}
  u \\
  v \\
  q \equiv \frac{1}{z}
\end{pmatrix}
\quad
\begin{pmatrix}
  du \\
  dv \\
  dq
\end{pmatrix}
\]

\[C_0 \equiv (R_0, T_0)\]
Initialisation of New Edgelets

- Highly non-Gaussian distributions in Cartesian coordinates

- Inverse-depth coordinates make the observation model nearly linear...

- ... so the estimate is better represented by a Gaussian.

Problem solved.
Initialisation of New Edgelets

- Highly non-Gaussian distributions in Cartesian coordinates
- Inverse-depth coordinates make the observation model nearly linear...
- ... so the estimate is better represented by a Gaussian.

Problem solved. This is a fib
The author demonstrates failure modes of the system
Thank you
Life-cycle of an Edgelet

1. Short, straight intensity step selected in image
2. Filter stores estimate in inverse depth (cylindrical distribution)
3. Uncertainty projected to image using UT
4. Change of Variables via UT to Cartesian
5. Further observations shrink uncertainty (EKF)
6. Observed again: UT yields Gaussian in inverse depth coordinates
7. Predict, observe, update (EKF)
8. Discard

Repeated Failures?