FEJ2: A Consistent Visual-Inertial State Estimator Design

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Introduction

- Filter-based visual-inertial estimators
  - 4 d.o.f unobservable ideally (yaw + pos.)
  - linearizing at current state estimates causes information gains in unobs.
  - Covariance becomes overconfident (inconsistent)

- First-estimates Jacobian (FEJ)
  - Fixes Jacobians at first estimates to enforce 4 d.o.f (consistent)
  - Fixes Jacobians introduce unmodelled errors

- We propose FEJ2
  - Addresses the unmodelled errors of FEJ
  - Shown to improve performance

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nonlinear measurement function

\[ z = h(x) + n \rightarrow \text{noise} \]

sensor measurement

\[ \hat{r} = z - h(\hat{x}) \approx \tilde{H}\hat{x} + \Delta H\hat{x} + n \]

\[ \Delta U^T \hat{r} = \Delta U^T \tilde{H}\hat{x} + \Delta U^T \Delta H\hat{x} + \Delta U^T n \]

\[ r^* = H^*\hat{x} + n^* \]

**FEJ**
- Evaluate the measurement Jacobian at the first state estimate
- Assumes \( \Delta H \) is zero to improve consistency
- Introduce unmodelled errors

**FEJ2**
- \( \Delta H = \hat{H} - \bar{H} \) captures linearization point changes between the first and best state estimates
- Project onto the nullspace of \( \Delta H \) to remove
- Keeps the correct unobservable subspace
- Better consistency than FEJ
Results and Conclusion

- Simulate inertial and bearing measurements under different VINS frameworks
- Monocular and stereo measurements
- Different measurement noise

<table>
<thead>
<tr>
<th>Noise (pixel)</th>
<th>Est.</th>
<th>RMSE Ori. (deg)</th>
<th>RMSE Pos. (m)</th>
<th>NEES Ori.</th>
<th>NEES Pos.</th>
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<tbody>
<tr>
<td></td>
<td></td>
<td>mono / stereo</td>
<td>mono / stereo</td>
<td>mono / stereo</td>
<td>mono / stereo</td>
</tr>
<tr>
<td>1</td>
<td>STD</td>
<td>0.412 / 0.344</td>
<td>0.130 / 0.109</td>
<td>23.874 / 15.447</td>
<td>4.911 / 4.874</td>
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<tr>
<td></td>
<td>OC</td>
<td>0.242 / 0.257</td>
<td>0.119 / 0.100</td>
<td>3.290 / 3.599</td>
<td>3.540 / 3.416</td>
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<tr>
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<td>FEJ</td>
<td>0.242 / 0.256</td>
<td>0.120 / 0.100</td>
<td>3.284 / 3.438</td>
<td>3.617 / 3.322</td>
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<td></td>
<td>FEJ2</td>
<td>0.238 / 0.238</td>
<td>0.118 / 0.095</td>
<td>3.150 / 3.324</td>
<td>3.443 / 2.965</td>
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<tr>
<td>3</td>
<td>STD</td>
<td>2.139 / 0.888</td>
<td>0.402 / 0.310</td>
<td>207.221 / 33.852</td>
<td>13.212 / 7.235</td>
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<td>OC</td>
<td>0.716 / 0.723</td>
<td>0.301 / 0.300</td>
<td>3.964 / 4.395</td>
<td>5.051 / 4.839</td>
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<td>0.861 / 0.704</td>
<td>0.289 / 0.298</td>
<td>4.965 / 4.163</td>
<td>4.763 / 4.656</td>
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<td>FEJ2</td>
<td>0.650 / 0.663</td>
<td>0.264 / 0.277</td>
<td>3.198 / 3.790</td>
<td>3.581 / 3.636</td>
</tr>
</tbody>
</table>

FEJ2 achieves better consistency and accuracy!

Summary

- Develop a novel consistent estimator design for VINS
- FEJ2 accurately models linearization errors of FEJ
- Theoretical proofs, simulations and real-world experiments show FEJ2 achieves better performance

Thank you!
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