Offloading UAV Navigation Computation to the Cloud

Sriramya “Ramya” Bhamidipati and Grace Xingxin Gao
UAV Navigation in Urban Areas

- Challenges
  - Limited battery life
  - Restricted cost and weight
  - Finite computational capacity
  - Standalone GPS not sufficient

[iBQR Quadrotor, Prof. Grace Gao’s research group]
Objectives

- Improve the position accuracy of UAV in urban areas
- Optimize on-board computational load

UAVs flying in urban area
Outline

• Approach
• Cloud-based GPS and Vision Fusion
• Setup and Evaluation
• Experimental Results
• Summary
Approach: Access to the Cloud

• Access to internet: WiFi, cellular, etc.

• Uses of the Cloud:
  – Low cost
  – Unlimited storage
  – High computing capacity
  – Access to online database
  – Huge infrastructure reduction

[NYC Opendata] WiFi hotspots in NYC
Approach: Various Sensors

- **GPS**
  - Global coverage
  - Reliable high elevation satellite data

- **Multiple cameras**
  - Rich visual features
  - Feature tracking

- **GPS and vision fusion**
  - Sensors aid each other
  - Better accuracy
Outline

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Architecture

- Pseudo ranges
- Weighted pseudoranges
- Coarse position
- Position & heading
- Keypoints

- GPS Satellite Module
- Street View Module
- Camera Module

- Street View Database
- Raw Images
Architecture

- GPS Satellite Module
- Street View Module
- Camera Module

- Pseudo ranges
- Maximum Likelihood Estimation
- Coarse position
- Weighted pseudoranges
- Position & heading

- Raw Images
- Optimized map points
- Keypoints

- Tracking Output
- Corrected position and heading

- Global Map Optimization
- Loop Closure Detection

Street View Database

Camera Module

Global Map

Optimization

Loop Closure Detection

Mapping
Architecture: Offload to the Cloud

- GPS Satellite Module
- Street View Module
- Camera Module

- Pseudo ranges
- Weighted pseudoranges
- Coarse position
- Position and heading
- Corrected position and heading
- Keypoints
- Maximum Likelihood Estimation

Mapping

- Global Map Optimization
- Loop Closure Detection

Modules offloaded to the Cloud

Tracking Output

Street View Database

Raw Images

Optimized map points
Architecture: Offload to the Cloud

Street View Database

GPS Satellite Module

Street View Module

Camera Module

Modules offloaded to the Cloud

Raw Images

Optimized map points

Mapping

Global Map Optimization

Loop Closure Detection

Pseudo ranges

Weighted pseudoranges

Coarse position

Position & heading

Keypoints

Corrected position and heading

Tracking Output

Maximum Likelihood Estimation

Raw Images
Street View Module - #1

- Extended Street View image database
  - Account for viewpoint changes
- Constrained multi-camera setup
  - Resolve ambiguities due to similar looking architecture
Street View Module - #2

- Image compression
  - Haar wavelets
- GIST - Global descriptor
  - Low dimensional semantic segmentation
  - Choose the potential image candidates
- SURF - Feature descriptor
  - Invariant to scale, illumination and rotation

Image compression

Extended Google Street View database

Scene evaluation based on GIST

Selected candidates

Constrained feature matching using SURF

Coarse position

Offloaded to the cloud
GPS and Vision Fusion

Street View module and motion model → Coarse Position

GPS satellite module

Pseudo ranges

Images

ORB feature based tracking

Optimized map points

Position & heading

Keypoints

Maximum likelihood position

Across the position candidates in search space

Global $\text{Pose}_E$

Mapping

University of Illinois at Urbana-Champaign
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# Communication Setup

- Robot Operating System (ROS) setup on UAV and Cloud
- Google Cloud Platform – compute engine used for the Cloud based computations

<table>
<thead>
<tr>
<th>Modules in the Cloud</th>
<th>Execution details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Image compression</td>
<td>1 compressed image 70kB bandwidth</td>
</tr>
<tr>
<td>Street View module</td>
<td>UDP link when sufficient bandwidth</td>
</tr>
<tr>
<td>Mapping module</td>
<td>TCP link when high bandwidth</td>
</tr>
</tbody>
</table>

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iBQR Quadcopter
ROS Master - #1
ROS Master - #2
Computational Time

- Latency depends on location of data center
- Implemented 8-core parallel processing on the Cloud

<table>
<thead>
<tr>
<th>Regions</th>
<th>Latency involved (ms)</th>
</tr>
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<tbody>
<tr>
<td>US-west</td>
<td>91.5</td>
</tr>
<tr>
<td>US-east</td>
<td>59.0</td>
</tr>
<tr>
<td>US-central</td>
<td>32.2</td>
</tr>
<tr>
<td>Europe-west</td>
<td>131</td>
</tr>
</tbody>
</table>

US-central zone

<table>
<thead>
<tr>
<th>Mode of transmission</th>
<th>Bandwidth available</th>
</tr>
</thead>
<tbody>
<tr>
<td>Downlink</td>
<td>Upto 9 Mbps</td>
</tr>
<tr>
<td>Uplink</td>
<td>Upto 5 Mbps</td>
</tr>
</tbody>
</table>
Outline

- Approach
- Cloud-based GPS and Vision Fusion
- Setup and Evaluation
- Experimental Results
- Summary
Outdoor UAV: Experiment Video
UAV Flight on UIUC Campus

Our approach achieved higher accuracy than the commercial GPS solution
### Computational Time

<table>
<thead>
<tr>
<th>Methodology</th>
<th>Latency</th>
<th>Image compression</th>
<th>Computation</th>
</tr>
</thead>
<tbody>
<tr>
<td>On-board computation with brute-force Street View</td>
<td>---</td>
<td>--</td>
<td>~89.2s</td>
</tr>
<tr>
<td>On-board computation with our Street View module</td>
<td>--</td>
<td>--</td>
<td>~15.4s</td>
</tr>
<tr>
<td>Cloud-based computation with our Street View module</td>
<td>31.2ms</td>
<td>7.3ms</td>
<td>~1.24s</td>
</tr>
</tbody>
</table>
Downtown Chicago: Setup

- Street View database of radius 1km considered
- GPS and two cameras (forward and sideways)

Top View of the car

- Ublox GPS receiver
- Side: Matrixvision bluefox camera
- Front: Dashcam
Downtown Chicago: Video
Our approach achieved high accuracy and takes about ~1.7s to process a single time instant.
Summary

- Developed a Cloud-based GPS and vision fusion technique for UAV navigation
- Optimized the UAV on-board computational load
- Verified the position accuracy through different urban experimental scenarios
Acknowledgements
Downtown Chicago: Street View

Multiple camera Street View localization more robust than a single camera case