Network Topology and Geometry

• Complementary:
  – **Topology** of the camera graph: connectivity and transitions between cameras
    • Fuel truck #538 was seen in camera 3 at 5:39pm, in camera 4 at 5:41pm,…
  – **Geometry**: where cameras are looking
    • Fuel truck #538 was heading toward the power plant between 5:39pm and 5:41pm

*Note: all images adjusted for presentation purposes*
Motivating Scenario

• Large network of cameras
  – *i.e.* hundreds or thousands
  – Location unknown, *e.g.*
    • Existing installations
    • Very rapid physical installation requirements

• Regular traffic instrumented with GPS receivers (patrols, service vehicles, *etc.*)

• ...need to know camera locations
Cameras as Tripwires

- This paper:
  - Narrow field-of-view (relative to GPS resolution)
  - Camera as a tripwire
Input Data (1)

- Time instants when each camera observed a vehicle entering or exiting: \( \{ t_{cj} \} \)
  - Vehicle identity not known
Input data (2)

• GPS Tracks (5 vehicles): \{((lat_{vi}, lon_{vi}, t_{vi}))\}
  – Not known: when a particular vehicle is seen in a particular camera

\[ p(\text{vehicle @ lat, lon}) \] abbreviated as \[ p(lat, lon) \]
Estimation: What We Want

\[ \hat{p}(lat, lon|lat, lon \in \text{camera}) \]

…but, we don’t know when a specific instrumented vehicle is visible

**Camera location:** probability \((lat, lon)\) being in the field of view = \(p(\text{vehicle being at } (lat, lon) \text{ when the camera is tripped})\)
Estimation: What We Get

\[
\hat{p}(\text{lat, lon} | \text{lat, lon} \in \text{camera}) = (1 - \alpha)\hat{p}(\text{lat, lon} | \text{lat, lon} \in \text{camera}) + \alpha p(\text{lat, lon})
\]
Camera Sees Nothing

\[ \hat{p}(\text{lat, lon}|\text{lat, lon } \in \text{camera}) = (1 - \alpha)\hat{p}(\text{lat, lon}|\text{lat, lon } \in \text{camera}) + \alpha p(\text{lat, lon}) \]
Camera Sees a GPS Vehicle

\[ \hat{p}(\text{lat}, \text{lon}|\text{lat}, \text{lon} \in \text{camera}) = (1 - \alpha)\hat{p}(\text{lat}, \text{lon}|\text{lat}, \text{lon} \in \text{camera}) + \alpha p(\text{lat}, \text{lon}) \]
Camera Sees Nothing

\[ \hat{p}(\text{lat, lon}|\text{lat, lon} \in \text{camera}) = (1 - \alpha)\hat{p}(\text{lat, lon}|\text{lat, lon} \in \text{camera}) + \alpha p(\text{lat, lon}) \]

\[ = (1 - \alpha) \]

[Images showing GPS-instrumented and non-instrumented vehicles]
Camera Sees a Distracter

\[
\hat{p}(\text{lat, lon}|\text{lat, lon} \in \text{camera}) = (1 - \alpha)\hat{p}(\text{lat, lon}|\text{lat, lon} \in \text{camera}) + \alpha p(\text{lat, lon})
\]
Best Cluster of Peaks

\( \tilde{p}(\text{lat}, \text{lon}|\text{lat}, \text{lon} \in \text{camera}) = (1 - \alpha)\hat{p}(\text{lat}, \text{lon}|\text{lat}, \text{lon} \in \text{camera}) + \alpha p(\text{lat}, \text{lon}) \)

\[ \tilde{p}(\text{lat}, \text{lon}|\text{lat}, \text{lon} \in \text{camera}) \]

\( h(\hat{p}) \ll h(p) \rightarrow \text{look for peaks} \)
Results

- Bright red squares: estimated camera fields of view
- Dark red trapezoids: ground truth (rough)
- Light green dots: peaks in $\tilde{p}(x, y|c)$
- Dark green dots: non-peak votes in $\tilde{p}(x, y|c)$
Conclusions

• No given correspondence

• Topology
  – Tripwire data $\rightarrow$ network topology and transitions
  – Can model appearance changes

• Geometry
  – Tripwire data + GPS side information $\rightarrow$ camera locations
Questions…

Thank you
Extra Slides...
Location + Pose

Voting Spaces
• Conditioned on Traffic Direction

Best Estimate Overlaid on a Satellite Map*

*true satellite image substituted
Sample Simulated Network

- 40 Intersections
- 80 Roads
- 8 Vehicles

- 10 Cameras
- Total road length: 4.2km
- Mean speed: 60kph

Rendering of Network
(with one camera circled)

Estimated (red) / Actual (green)
Camera Location
Simulation Results

Localization Error vs. # Vehicles

- 20 Roads
- 40 Roads
- 80 Roads

Voting shape size
Calibration

• Traditional calibration:
  – pixels ↔ object coordinates

• Geodetic calibration:
  – pixels ↔ (latitude, longitude)

• This paper:
  – Narrow field-of-view (relative to GPS resolution)
  – Camera as a tripwire
Why Not Just…

...take a GPS reading on the camera?

- **It’s hard:** GPS signals often blocked
- **It’s wrong:** Need GPS readings of the imaged area, not of the camera

...manually correspond image points to GPS readings?

- Hazardous environments
- Advertises boundaries of surveillance
- Does not scale well to hundreds or thousands of sensors that may be distributed