Real-Time Trajectory Refinement with Probablistic Rules

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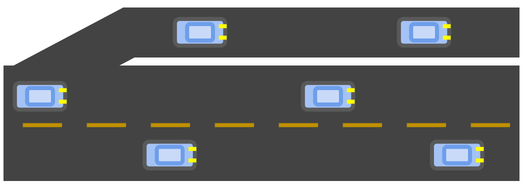

Figure 1: Motivating Example: Differentiating vehicles on nearby parallel roads

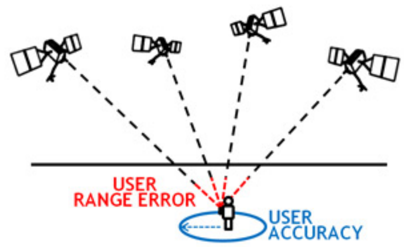

Figure 2: GPS Technology Overview. *Source: gps.gov*

1. Introduction

Many systems today keep track of objects in real-time through positioning technologies such as the satelite Global Positioning System (GPS). However, positioning technologies have inherent error, which can range from centimeters to tens of meters. Consider the issue of tracking the number of vehicles exiting a highway to an adjacent, parallel frontage road (Figure 2). All vehicles are still going in the same direction, at similar speeds. The difference in relative position could easily be within the error of GPS under poor conditions.

This problem can be handled in a number of different ways. If additional sensors can be used, then disparate information can be combined to produce more accurate results, known as *sensor fusion*. Alternatively, historical sensor information can be used to refine new sensor inputs. Finally, rules can be introduced to help clean up random information. Returning to our example, if the vehicle velocity drops below highway speeds over a period of time, it could be assumed to have left the faster roadway.

This work combines historical information with probablistic rules, using techniques similar to sensor fusion to combine continuous probabilities. Continuous probability spaces of position and velocity are approximated with 4-dimensional meshes, which can be efficiently combined to refine location estimates.

2. Background

2.1 GPS Positioning

GPS Positioning technology makes use of satelites in known orbits around the earth, broadcasting the current time. By consulting the orbits and the time taken for a signal to arrive from a number of satelites, GPS recievers can determine their own location on Earth, as shown in Figure **??**.

Taylor: Discuss how GPS functions

Taylor: Discuss GPS failure modes, use gps.gov

2.2 Trajectory Refinement

Taylor: Discuss intuition of combining estimates with sensors, rules

Taylor: Discuss difficulty of evaluation, cite others with issue

3. Related Work

3.1 Kalman Filters

3.2 Map Matching

3.3 Probability Grids

Taylor: Resummarize work as agenda

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4. Probability Grid

Taylor: Detail problem of discretizing continuous probs Taylor: cite original 2d grid work Taylor: discuss extension to 4d to include velocity

Taylor: Discuss 2-way mapping from grid to real-world Taylor: Discuss implementation of linear interpolation Taylor: Discuss benefits/drawbacks of linear interpolation=¿max/min at point

5. Probabilistic Rules

Taylor: Discuss ability to represent knowledge of objects being tracked Taylor: Contrast to Kalman Filters, which can only represent Gaussians Taylor: Provide examples: Vehicles drive on roads, in the correct direction, people near their home not moving are in their homes Taylor: Emphasize probability to allow rules that are sometimes wrong

5.1 Road Matching

Taylor: Discuss and cite data source (OSM)

Taylor: Give function over minimum road distance

Taylor: Efficiently calculating minimum road distance Taylor: discuss roads: sequence of segments Taylor: discuss index implementation - each road in each grid cell it crosses Taylor: discuss index query - need query point + neighbors (nearest q, not overlap q)

6. Grid-Based Trajectory Refinement

Taylor: summarize how grids + rules can combine information

6.1 Forward Estimation

Taylor: Describe example point in grid with velocity moving forward Taylor: provide math for pointwise update

6.2 GPS Sensor Integration

Taylor: Describe sensor input, gaussian centered around point Taylor: Cite error distribution again Taylor: provide math for pointwise integration Taylor: Call out mult as pointwise AND

6.3 Rule Integration

Taylor: Call back to sensor integration Taylor: Note equation compatibility with any probability rule Taylor: Summarize use of OSM Road Matching

7. Evaluation

Taylor: Describe input data Taylor: Describe experimental setup

7.1 Processing Time

Taylor: Faster better, but hard constraint: must keep up with world Taylor: describe Grid fidelity importance Taylor: Describe recoverability Taylor: describe sources of error

Taylor: generate and reference graph Taylor: describe error metric: difference at each timestamp Taylor: Show 256*256 as apparent sweet spot

7.2 Route Recoverability

Taylor: Describe assumed GPS unreliability Taylor: random permutations to location, scaling distance Taylor: compare distance between original/permuted locations vs original/permuted grid locations

Taylor: generate and reference graph Taylor: discuss reasons for failure: error magnification Taylor: discuss reasons for failure: falling off grid

8. Conclusion

9. Future Work

References