Gnome: A Practical Approach to NLOS Mitigation for GPS Positioning in Smartphones

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GPS Location is Important for Mobile Computing

- Personal Navigation
- Internet of Things
- Ads & Business Intelligence
- Ride Sharing

Motivation | Background | Challenges | Solutions | Evaluation
Location Accuracy Drops in Urban Canyons

Motivation

Background

Challenges

Solutions

Evaluation
Location Accuracy Drops in Urban Canyons

Bad GPS accuracy affects many applications

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How GPS Uses Satellite Signals

- Each satellite continuously broadcasts its current location and time
- GPS receiver computes location using the distance to each satellite
Key Reason: Non-Line-of Sight Satellite (NLOS) Signals

Line-of-sight (LOS)

Non-line-of-sight (NLOS)
NLOS Signals Can Inflate Satellite Signal Paths

The measured travel distance is longer in NLOS case

[Diagram showing NLOS signal with an extra path due to reflection plane]
The NLOS path inflation could cause >100m of location error.
Goal: Estimate the Path Inflation and Improve GPS Accuracy
Challenges

- How to compute path inflation
- How to use path inflation to help estimate position
- How to run the workflow on the phone real-time
Contributions

- **How to compute path inflation**
  Leverage public depth information with building height adjustment for accurate path estimation

- **How to use path inflation to help estimate position**
  Search most likely ground truth position from candidates

- **How to run the workflow on the phone real-time**
  Pre-compute path inflation maps in the cloud
Contributions

Localization error 55%

Speed on the phone > 15 Hz
How to compute path inflation
Leverage public depth information with building height adjustment for accurate path estimation

How to use path inflation to help estimate position
Design a path-inflation-based metric for accurate positioning

How to run the workflow on the phone real-time
Speedup the computation on mobile devices
Estimate Path Inflation using 3D models

Satellite position is available in received GPS signal

Ray-tracing with 3D model can predict the signal reflection
Prior Work Uses Commercial 3D models or Mobile Cameras

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Insight: Google Street View has 3D Models for Many Cities

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Evaluation
Accurate building surfaces are essential for ray tracing.

Drawback: Some Buildings’ Surfaces are Incorrect
Our Approach: Building Height Estimation

1) Skyline detection

2) Elevation estimation

Solutions

Motivation  Background  Challenges  Evaluation
Our Approach: Building Height Estimation

3) Height Estimation
Our Approach: Building Height Estimation

4) Robust Height Estimation
Our Approach: Building Height Estimation

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Motivation | Background | Challenges | Solutions | Evaluation
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- How to run the workflow on the phone real-time
  Speed up the computation on mobile devices
Modern Phones Are Starting to Provide Detailed GPS Data

The Android APIs provide satellite positions, signal propagation time, signal-noise-ratio, etc.

Can be used for position re-calculation after path adjustment
Calculated the Adjusted Position with Path Inflation Known

Calculate the path inflation

Wrong location with path inflation

Compute the adjusted location

Correct location
We cannot know the receiver ground-truth location for ray-tracing.
Ray-tracing from different position will give various path inflation estimate.
Key Insight: Minimum Adjustment is Likely Closest to Ground Truth
1. Select candidates near the original GPS output

2. Calculate location adjustment for each candidate

3. Output the candidate with minimum adjusted error
Search Candidates for the Best Position

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2. Calculate location adjustment for each candidate
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Path Inflation is Infeasible on Phones

Tens of minutes to process ray-tracing for candidates on one street

Precompute Path Inflation on Cloud
Pre-Compute Path Inflation

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Pre-Compute Path Inflation
Pre-Compute Path Inflation

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Pre-Compute Path Inflation

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Inflation Model
Gnome Cloud and Mobile Components

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Gnome Cloud

Panorama

& 3D Planes

Estimating Path Inflation

Gnome Cloud

Inflation Model

Satellite position & data

Location Prediction

Gnome Mobile

Result

User’s Phone
Tested Gnome on four models of Android phones
Collected 4.7km (walking) and 9.3km (driving) traces
85.6% GPS readings can see fewer than four LOS satellites
Gnome reduces > 50% of average error in static and walking scenarios
Dead-reckoning and map matching benefit the phones in the driving case.
Street View 3D models are widely available in many parts of the world.
Gnome reduces location error by up to 50% in the four major cities.
Speed

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User’s Phone

Result
Conclusion

- Most GPS errors in urban canyons are caused by **NLOS path inflation**
- Gnome leverages **Google Streetview and NLOS mitigation** to correct the GPS localization results
- Gnome **corrects the building height** of street models to improve the localization accuracy
- Gnome **pre-computes the path inflation** to make the mobile app run fast
- Gnome **reduces the positioning error by up to 55%** on Android phones