Indoor Positioning Using GPS Revisited

Mikkel Baun Kjærgaard , **Henrik Blunck** , Torben Godsk , Thomas Toftkjær ,
Dan Lund Christensen , and Kaj Grønbaek

Overview

- › Motivation
- › GPS and alternative positioning technologies
- › Recent advances: High-Sensitivity and Assisted GPS
- › Evaluating GPS performance indoors
- › Measurement campaign results
- › The future in GPS and indoor positioning

MOTIVATION

› Applications require positioning with indoor coverage

Indoor Pedestrian

Advanced Farming

Search&Rescue: Coordinating Fire Fighters

› Scenarios from a pervasive positioning project run at Aarhus University (<http://cs.au.dk/research/centers-and-projects/galileo/>)

MOTIVATION

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1. Pervasive Coverage

- › Applications work where needed

2. Independence from Local Infrastructures

- › No need to setup and maintain local infrastructure.
- › Reliability (e.g. fire fighting)

› Global Navigation Satellite Systems (e.g. GPS)

- › Satisfying 2. (Space segment, Control segment, A-GPS)
- › Previously GPS did only work outdoors and therefore did not satisfy 1.
- › **How are the advances in technology changing this situation?**

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GPS and Alternative Technologies

Anthony LaMarca, Eyal de Lara: Location Systems: An Introduction to the Technology Behind Location Awareness, Morgan & Claypool Publishers, 2008

› Inertial Positioning

Oliver Woodman, Robert Harle: RF-Based Initialisation for Inertial Pedestrian Tracking. Pervasive 2009: 238-255

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High-Sensitivity and Assisted GPS

› Problem - Tune into the signals

- › A search problem where we have to find a peak

- › In weak signal conditions the peak is very small
-> disappears in background noise

› High-Sensitivity

- › Integrate signals over time to make the peak higher
- › Made possible by massive parallelization
  - › Old outdoor receiver: **36** correlations per second
  - › Modern receiver: **200.000+** correlations per second

High-Sensitivity and Assisted GPS

› Assisted GPS (A-GPS)

- › Providing the receiver with assistance data over other communication means (e.g. cellular networks)
- › Help with reducing the search space by
  - › Providing rough current time (± 2 seconds)
  - › Providing rough position (< 3 kilometers)

› Problem – Decoding navigation data

- › Navigation data needed to compute receiver position
- › In weak signal conditions the receiver cannot decode these data bits from the satellite signals.
- › A-GPS
  - › Navigation data provided as part of the assistance data

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GPS receivers employed in campaign

- › 2 classes of receivers were investigated:
  - › dedicated GPS receivers
  - › in-phone receiver systems
    - › → size, cost and power restrictions
- › Setup enforces limits on # receivers
  - › to avoid near-field interactions between receivers
- › → Example devices chosen for each class:
  - › dedicated U-blox LEA + external active patch antenna
  - › Nokia N95 in-phone GPS system
    - › Texas Instruments GPS chip + internal active patch antenna

Indoor environments investigated

wooden houses

brick houses

Warehouse

School building

Shopping mall

Tower block

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Indoor GPS performance levels measured

- › .. using a dedicated receiver, e.g. u-blox's
- › **Availability and time-to-first-fix**
  - › non-assisted GPS:
    - › often not available deep indoors; often TTFF > 1 min
  - › A-GPS:
    - › better availability and often TTFF < 5 sec (deep indoors: up to 3 min)
- › **Positioning accuracy** (in 2D RMS; using A-GPS)
  - › in smaller wooden / brick houses: ~ 4m / 7m
  - › up to 60m “deep indoors” in tower block
  - › Low accuracies caused by:
    - › signal attenuation → (poor constellations of) only few “visible” satellites
    - › multipath phenomena (i.e. strong signal echoes)

wooden houses

brick houses

Warehouse

School building

Shopping mall

Tower block

Hot and Cold Start

Hot Start

Tracking

Blocked

2D dimensions of building

number of stories

"challenge" for GPS positioning

brick houses

Warehouse

School building

Shopping mall

Tower block

GPS signal-to-noise-ratios

› Problem - Tune into the signals

- › A search problem where we have to find a peak

- › In weak signal conditions the peak is very small
-> disappears in background noise
- › GPS Satellite signal is sent with only $\sim 27\text{W}$
- › Noise levels at receiver: $\sim -200\text{ dBW/Hz}$
- › GPS signal strength at receiver:
  - › outdoors: $\sim -155\text{ dBW} \rightarrow \text{SNR: } 45\text{ dB/Hz}$
  - › deep indoors: often down to $-185\text{ dBW} \rightarrow \text{SNR: } 15\text{ dB/Hz}$
i.e. **1000 times weaker than outdoors**

Indoor GPS Performance: Availability

- › Main factor impairing availability:
  - › obstructing building elements
  - › cause signal attenuation

Building Type	Walls				Roof	dB
	External	dB	Internal	dB		
Wood 1	Wood	2.40	Wood	2.40	Tiles	5.19
Wood 2	Wood	2.40	Wood	2.40	Tiles	5.19
Brick 1	Double Brick	10.38	Brick	5.19	Fiber Cement	N/A
Brick 2	Double Brick	10.38	Brick	5.19	Tiles	5.19
School main building + right wing annex + left wing	Double Brick	10.38	Brick	5.19	Tiles	5.19
	Brick and Concrete	14.76	Concrete	9.57	Tiles	5.19
Warehouse	Fiber Cement and Curtains/Openings	N/A N/A	Equipment	N/A	Fiber Cement	N/A
Shopping Mall	Reinforced Concrete	16.70	Brick	5.19	Flagstone	N/A
	Tinted Glass	24.44			Sand	2
	Glass	2.43			Felt roofing	N/A
Tower block	Double Brick around Concrete	19.95	Brick	5.19	Concrete	9.57
					Tiles	5.19

Indoor GPS Performance: Availability

- › Main factor impairing availability:
  - › obstructing building elements
  - › cause signal attenuation (**additive**)
  - › .. and **dispersion** → user's distance from elements crucial

Challenges in Indoor GPS Positioning

- › Outdoors: Satellites overhead received stronger
- › Less so indoors; esp. on lower floors of tall buildings
  - › signal (versions) stronger through windows than through roof
  - › echoes cause pseudorange errors!

Tower block

Challenges in Indoor GPS Positioning

- › Outdoors: Satellites overhead received stronger
- › Less so indoors; esp. on lower floors of tall buildings
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  - › echoes cause pseudorange errors!

Tower block

Hot and Cold Start

Hot Start

Tracking

Blocked

Shopping mall (242m x 150m)

“signals are wanted strong... but if they are: don’t trust them”

Hot and Cold Start

Hot Start

Tracking

Blocked

Shopping mall (242m x 150m)

Shopping mall (242m x 150m)

GPS performance: Availability/Accuracy

> Shopping mall (242m x 150m)

Indoor GPS Performance: Accuracy (in RMS)

- › Outdoors: 3m
- › In houses on average: ~5m
- › In shopping mall on average: ~15m

Indoor GPS Performance: Accuracy (in RMS)

- › Expected: vertical error larger than horizontal one
- › Measured: **Less so** in buildings

GPS Positioning: Dilution of Precision (DOP)

- › DOP value: maps “quality” of satellite configuration
- › Positioning error: expected to grow linearly with DOP

Indoor GPS Performance: time-to-first-fix

- > Outdoor hot / cold starts: 1s / 29s (u-blox specs)
- > In houses on average: 4s / 40s
- > In shopping mall on average: ~ 10s / 60s

Indoor GPS Performance: Accuracy (in RMS)

- > Outdoors: ~3m
- > In houses on average: ~5m
- > In shopping mall on average: ~15m

Indoor GPS Performance: Accuracy (in RMS)

> w.r.t. positioning accuracy, for both 2D and 3D RMS:
“order of difficulty” of environments identical

Indoor GPS performance: Accuracy (CDFs)

> w.r.t. positioning accuracy, for all confidence levels:
“order of difficulty” of environments identical

GPS performance factors: Receiver type

- › Recent developments in in-phone GPS technology:
  - › Sensitivity improved by “almost 1 000 times”
  - › → phones now use “cheaper antennas” [van Diggelen]

- › In-phone campaign results, U-blox vs. **Nokia N95**:
  - › Availability, e.g. in shopping mall: 77% / **63%**
  - › Accuracy (in 2D RMS) on average:
    - › In houses: ~5m / **10m**
    - › In shopping: ~15m / **20m**
  - › Time-to-first-fix on average:
    - › In houses: 2s / 40s / **10s**
    - › In shopping mall: ~ 10s / 60s / **90s**

- › In-phone GPS performance levels improving..
but **still** worse than for dedicated receivers

GPS performance factors: Receiver type

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Accuracy (in 2D RMS): U-blox

- › Outdoors: 3m
- › In houses on average: ~5m
- › In shopping mall on average: ~15m

Accuracy (in 2D RMS): U-blox vs. **Nokia N95**

- > Outdoors: ~3m / **6m**
- > In houses on average: ~5m / **10m**
- > In shopping mall on average: ~15m / **20m**

Time-to-first-fix: U-blox

> In houses on average: 2s / 40s

> In shopping mall on average: ~ 10s / 60s

Time-to-first-fix: U-blox vs. **Nokia N95**

> In houses on average: 2s / 40s / **10s**

> In shopping mall on average: ~ 10s / 60s / **90s**

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Indoor GPS: Future Directions

- › Improvements for mobile gadgets' GPS:
  - › antenna design, component integration, energy-efficiency..

- › Fusion with other positioning technologies
  - › with IMUs (Inertial Measurement Units)
    - › GPS “cures” error growth of IMUs over time

- › Utilizing data about the user's current environment
  - › identify satellites received only indirectly
  - › correct for multipath errors using ray-tracing

Upcoming Indoor GPS Improvements

- › modernized GPS signals (2013)
  - › better multipath protection
  - › easier weak signal acquisition
- › interoperable GNSSs, e.g. GPS and Galileo (2015)
  - › additional satellites provide better constellations
  - › → improved availability and accuracy especially indoors!

Future Indoor GPS: Directions

- › Fusion with other positioning technologies
  - › with IMUs (Inertial Measurement Units)
    - › deep integration → GPS signal tracking down to 1.5dB [Pany et.al.]

At demo session: Demonstrating Tools and Results of a Measurement Campaign for Indoor GPS Positioning

Thank you for your attention!