Application: RSS SLAM

Sensor Fusion

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Indoor Positioning for First Responders

- MSc thesis at FOI 2014.
- Navigation support for:
  - Fire fighters
  - Police
  - Rescue personnel
- GNSS not available indoors.
- WiFi may be inaccessible or not installed.
- Floor plan may be unavailable.
- Requirements:
  - Room level accuracy.
  - Independent of pre-installed infrastructure, maps and other *a priori* information.
  - Price, size and weight.

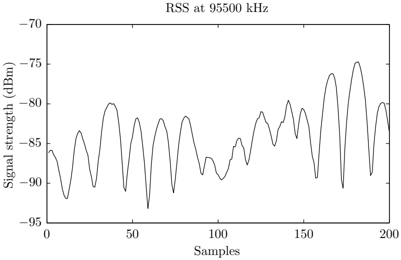
Opportunistic RSS

Standard fingerprinting use:

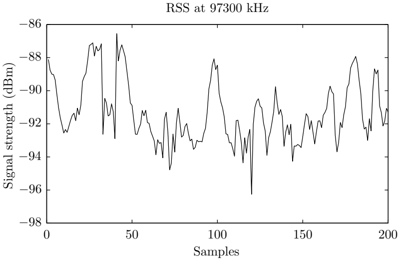
- Pre-determined WiFi maps.
- Access point ID's.

Apply the SLAM concept:

- Loop-closure enables drift correction.
- Map consist of RSS fingerprints for previously visited locations.



Experimental data collection setup.



Gaussian Process Model for RSS Prediction: the map

- Each component in the fingerprint vector is assumed to be a *Gaussian process* (GP)

$$\mathcal{F} \sim \mathcal{GP}(\mathcal{M}, \mathcal{K}),$$

  which is a distribution function of the position x.
- $\mathcal{M}(x)$ is a mean function.
- $\mathcal{K}(x, x')$ is a covariance function.
- The involved functions are estimated from (noisy) RSS training data.
- Sparse approximation using radial basis functions.
- The estimated GP's can then be used to prediction measurements.

Foot-Mounted INS

- Dead-reckoning system *inertial navigation system* (INS).
- Method:
  - Double integrate accelerometer signals.
  - Integrate gyroscope signals.
  - Apply *zero-velocity-updates* (ZUPT)'s.
- Heading error dominates.

Motion Model from INS

A motion model based on the odometry from the foot-mounted INS:

$$x_{k+1} = x_k + \begin{pmatrix} r_k \cos(\phi_k - \beta) \\ r_k \sin(\phi_k - \beta) \\ T\dot{\beta} \\ 0 \end{pmatrix} + \begin{pmatrix} 0 \\ 0 \\ \frac{T^2}{2} \\ T \end{pmatrix} v_k,$$

$$u_k = \begin{pmatrix} r_k \\ \phi_k \end{pmatrix} = \begin{pmatrix} \|p_{k+1}^{INS} - p_k^{INS}\| \\ \angle(p_{k+1}^{INS}, p_k^{INS}) \end{pmatrix}$$

The state comprises:

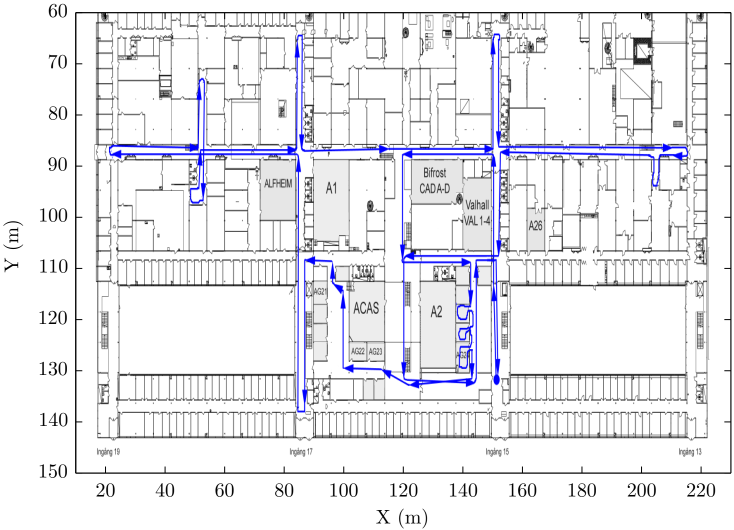
- Global position (x, y)
- Heading error, β (and $\dot{\beta}$ to form a CV)

Other states from the INS, such as velocities and angular rates are not used.

Putting It All Together

- Distributed particle filter SLAM.
- The map is stored in an *occupancy grid*.
- An *ancestry tree* keeps track of particle history and shared information.
- Efficient data structure.
- Memory requirements can be met by grid resolution adjustment.

Results: a walk in the A-building



https://youtu.be/1KD2vwmfNO0

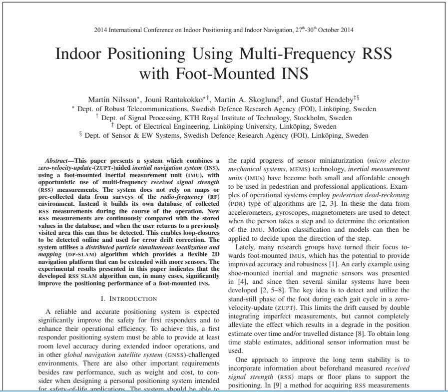
Results: a walk in the A-building

https://youtu.be/1KD2vwmfNOO

Master's Thesis Outcome

Martin Nilsson, Jouni Rantakokko, Martin Skoglund, and Gustaf Hendeby. "Indoor Positioning Using Multi-Frequency RSS with Foot-Mounted INS". In: *5th Internal Conference on Indoor Positioning and Indoor Navgation (IPIN)*, Busan, Kora, 2014. **Runner up best paper award.**

- Master's thesis project at FOI by Martin Nilsson in 2014.
- Radionavigationsnämnden's best MSc thesis award.
- Runner up Dataföreningens best MSc thesis award.
- Details in the MSc thesis: `https://bit.ly/2VDleru`



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Indoor Positioning Using Multi-Frequency RSS with Foot-Mounted INS

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***Abstract*—This paper presents a system which combines a *zero-velocity-update*-(ZUPT-)aided *inertial navigation system* (INS), using a foot-mounted inertial measurement unit (IMU), with opportunistic use of multi-frequency *received signal strength* (RSS) measurements. The system does not rely on maps or pre-collected data from surveys of the *radio-frequency* (RF) environment. Instead it builds its own database of collected RSS measurements during the course of the operation. New RSS measurements are continuously compared with the stored values in the database, and when the user returns to a previously visited area this can thus be detected. This enables loop-closures to be detected online and used for error drift correction. The system utilises a *distributed particle simultaneous localization and mapping* (DP-SLAM) algorithm which provides a flexible 2D navigation platform that can be extended with more sensors. The experimental results presented in this paper indicates that the developed RSS SLAM algorithm can, in many cases, significantly improve the positioning performance of a foot-mounted INS.**

I. Introduction

A reliable and accurate positioning system is expected significantly improve the safety for first responders and to enhance their operational efficiency. To achieve this, a first responder positioning system must be able to provide at least room level accuracy during extended indoor operations, and in other *global navigation satellite system* (GNSS)-challenged environments. There are also other important requirements besides raw performance, such as weight and cost, to consider when designing a personal positioning system intended for safety-of-life applications. The system should be able to

the rapid progress of sensor miniaturization (*micro electro mechanical systems*, MEMS) technology, *inertial measurement units* (IMUs) have become both small and affordable enough to be used in pedestrian and professional applications. Examples of operational systems employ *pedestrian dead-reckoning* (PDR) type of algorithms are [2, 3]. In these the data from accelerometers, gyroscopes, magnetometers are used to detect when the person takes a step and to determine the orientation of the IMU. Motion classification and models can then be applied to decide upon the direction of the step.

Lately, many research groups have turned their focus towards foot-mounted IMUs, which has the potential to provide improved accuracy and robustness [1]. An early example using shoe-mounted inertial and magnetic sensors was presented in [4], and since then several similar systems have been developed [2, 5–8]. The key idea is to detect and utilize the stand-still phase of the foot during each gait cycle in a zero-velocity-update (ZUPT). This limits the drift caused by double integrating imperfect measurements, but cannot completely alleviate the effect which results in a degrade in the position estimate over time and/or travelled distance [8]. To obtain long time stable estimates, additional sensor information must be used.

One approach to improve the long term stability is to incorporate information about beforehand measured *received signal strength* (RSS) maps or floor plans to support the positioning. In [9] a method for acquiring RSS measurements