An Overview of Indoor Positioning for IoT Applications

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T-LADIES Kick-off Meeting

Indoor Positioning – Motivation

- While the problem of outdoor positioning can be considered as solved (GPS, Galileo), indoor positioning is still an open issue
- The aim is to locate a device with respect to a fixed reference frame in an indoor environment
- Different technologies have been experimented
  - E.g.: WiFi, Ultra Wide Band (UWB), Bluetooth, inertial sensors
- Interest for many applications
  - Industrial warehouses
  - Houses (e.g., to support ambient assisted living)
  - Large indoor areas, such as shopping malls and airports
  - Museums and exhibitions, to support location-aware games and serious games

Positioning vs. Localization

Positioning

- Find the position of a target with respect to a reference frame
  - (x, y, z) coordinates in 3D
  - (x, y) coordinates in 2D

Localization

- Find the relative position of a target with respect to a set of Points of Interests (PoIs)
  - `left_of(user, table)`
  - `in_front_of(user, portrait_1)`

The Positioning Problem

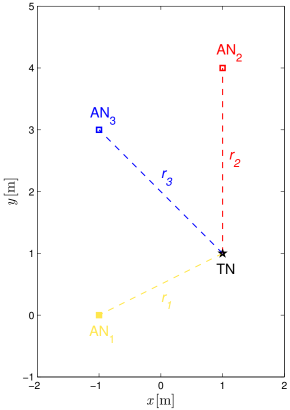
First Task: Distance Estimate

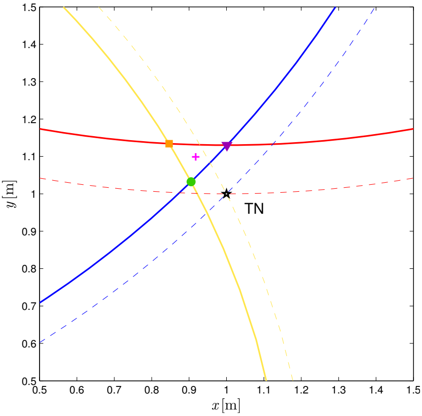
- The estimates of the distance between an *Anchor Node* (*AN*) and a *Target Node* (*TN*) are derived from the signals traveling between such nodes

Second Task: Position Estimate

- The estimates of the distances from the TN to a sufficiently large number of ANs need to be acquired
- The acquired distance estimates are processed
- An effective *positioning algorithm* is necessary to obtain an estimate of the position of the TN

The Need of a Positioning Algorithm





- Many distance-based positioning algorithms are available in the literature
- The choice can depend on the application scenario

The Positioning Scenario

Assumptions and Notation

- 3D scenario
- M ANs with known coordinates denoted as

$$\mathbf{s}_i \; = \; (x_i, y_i, z_i)^\mathsf{T} \qquad 1 \leq i \leq M$$

- TN position denoted as $\mathbf{u} \; = \; (x, y, z)^\mathsf{T}$
- True distance between the $i-$th AN and the TN

$$r_i = ||\mathbf{u} - \mathbf{s}_i|| \qquad 1 \leq i \leq M$$

- Estimated distance between the $i-$th AN and the TN

$$\hat{r}_i = r_i + \varepsilon_i \qquad 1 \leq i \leq M$$

The Positioning Problem

- The TN position $\mathbf{u} = (x, y, z)^\intercal$ can be found by considering

$$\begin{cases} (x - x_1)^2 + (y - y_1)^2 + (z - z_1)^2 = r_1^2 \\ \dots \\ (x - x_M)^2 + (y - y_M)^2 + (z - z_M)^2 = r_M^2 \end{cases}$$

- The TN position estimate $\hat{\mathbf{u}} = (\hat{x}, \hat{y}, \hat{z})^\intercal$ can be found by solving

$$\begin{cases} (\hat{x} - x_1)^2 + (\hat{y} - y_1)^2 + (\hat{z} - z_1)^2 = \hat{r}_1^2 \\ \dots \\ (\hat{x} - x_M)^2 + (\hat{y} - y_M)^2 + (\hat{z} - z_M)^2 = \hat{r}_M^2 \end{cases}$$

- The spheres represented in the previous system of equations do not intersect in a single point

Issues of Geometric-Based Approaches

Geometric-Based Positioning Algorithms

- The most common approaches to positioning involve geometric considerations
  - *Two-Stage Maximum-Likelihood* (*TSML*) algorithm
- The equations involved in the TSML algorithm can be ill-conditioned if the ANs are placed on the same plane
  - Typical in real indoor scenarios to maximize coverage and minimize multi-path interference
- More robust positioning algorithms are needed
  - To obtain more reliable results
  - To tailor algorithms to specific positioning scenarios

Experimented Technologies

WiFi

- WiFi is nowadays ubiquitous in indoor environments
- The received power of signals gives estimates of the distances

$$\bar{P}(r) = P_0 - 10\beta \log_{10} \frac{r}{r_0}$$

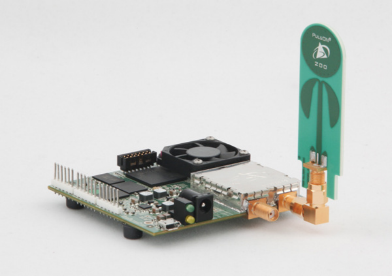
- Drawback: less accurate distance estimates

UWB

- UWB technology uses short high-frequency pulses
- The large bandwidth of UWB signals guarantees robustness to multi-path interference
- The time of flight of signals gives accurate estimates of the distances
- Drawback: need of a dedicated infrastructure

Applications to Real-World Problems

Positioning in Indoor Environments



Optimization-Based Approaches (I)

The TN position estimate $\hat{\mathbf{u}} = (\hat{x}, \hat{y}, \hat{z})^\mathsf{T}$ can be found by solving

$$\begin{cases} (\hat{x} - x_1)^2 + (\hat{y} - y_1)^2 + (\hat{z} - z_1)^2 = \hat{r}_1^2 \\ \dots \\ (\hat{x} - x_M)^2 + (\hat{y} - y_M)^2 + (\hat{z} - z_M)^2 = \hat{r}_M^2 \end{cases}$$

Optimization-Based Algorithms

The previous system of equations can be re-written as

$$\mathbf{1}\, \hat{\mathbf{u}}^\mathsf{T} \hat{\mathbf{u}} + \mathbf{A}\, \hat{\mathbf{u}} = \hat{\mathbf{k}}$$

where $\hat{k}_i = \hat{r}_i^2 - (x_i^2 + y_i^2 + z_i^2)$

$$\mathbf{A} = -2 \begin{pmatrix} x_1 & y_1 & z_1 \\ \vdots & \vdots & \vdots \\ x_M & y_M & z_M \end{pmatrix}$$

Optimization-Based Approaches (II)

Positioning as a Minimization Problem

- Using the previous reformulation, the positioning problem in an environment $D \subseteq \mathbb{R}^3$ can be written as a minimization problem

$$\hat{\mathbf{u}} = \arg\min_{\mathbf{u} \in D} F(\mathbf{u})$$

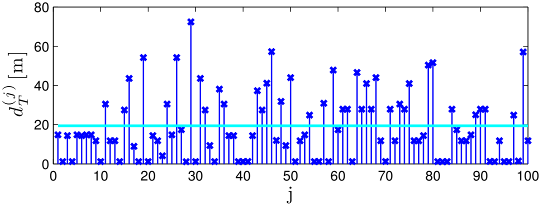
where $F(\mathbf{u})$ represents the *cost function*

$$F(\mathbf{u}) = ||\hat{\mathbf{k}} - (\mathbf{1}\,\hat{\mathbf{u}}^{\mathsf{T}}\hat{\mathbf{u}} + \mathbf{A}\,\hat{\mathbf{u}})||^2$$

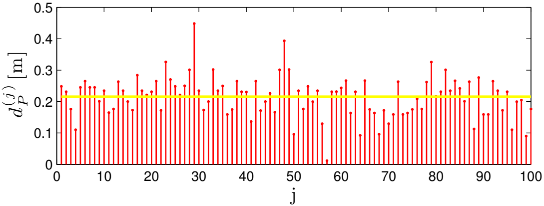
- One of the algorithms that can be used to solve the previous minimization problem is the *Particle Swarm Optimization* (*PSO*) algorithm

A Problematic Scenario

- ANs (almost) at the same height
- TN in the middle of the room



TSML

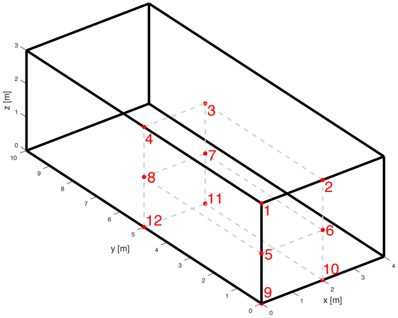


PSO

The POST Algorithm

- The *Polynomial Optimization using Subdivision Trees* (*POST*) algorithm has been recently proposed
- The POST algorithm uses techniques based on our research on polynomial constraints to solve the minimization problem derived from a positioning problem
- The POST algorithm estimates the position of the TN by finding a global minimum of a polynomial function of $n = 3$ variables and multi-degree $L = (4, 4, 4)$ over a given box, which corresponds to the considered environment
- Finite domain techniques are applicable, provided that a proper discretization of the space is considered

The POST Algorithm – Results



Position	e_P [m]	σ_P [m]
$\mathbf{t}_1$	0.750	0.380
$\mathbf{t}_2$	0.776	0.249
$\mathbf{t}_3$	0.220	0.416
$\mathbf{t}_4$	0.246	0.257
$\mathbf{t}_5$	0.515	0.185
$\mathbf{t}_6$	0.544	0.237
$\mathbf{t}_7$	0.727	0.241
$\mathbf{t}_8$	0.603	0.182
$\mathbf{t}_9$	0.241	0.097
$\mathbf{t}_{10}$	0.488	0.227
$\mathbf{t}_{11}$	0.309	0.215
$\mathbf{t}_{12}$	0.500	0.156

On the plane $z = 1$ m, the error on each distance estimate is typically between 0.1 m and 0.2 m.

The Need for...

- Programming language support for positioning and localization
- Integration with software agents and agent-oriented programming languages
  - Dedicated datatypes
  - Periodical operations
  - Asynchronous operations
  - ...
- Customization and fine-tuning with respect to the execution environment
  - The processing power dictates positioning or localization
  - The battery charge influences the accuracy of positioning
  - ...

Thank You for Your Attention

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