UWB-based Single Reference Point Positioning System

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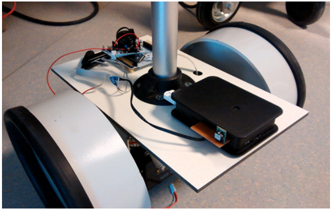
May 8, 2017

Introduction

- Positioning is used in industrial, medical and consumer applications.
  - Industrial applications: good monitoring, plant security.
  - Medical applications: fall detection, equipment monitoring.
  - Consumer applications: smart gadgets, keyfinder.
- New application emerge:
  - Autonomous driving.
  - ...



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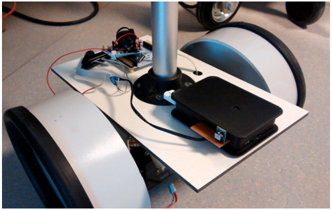
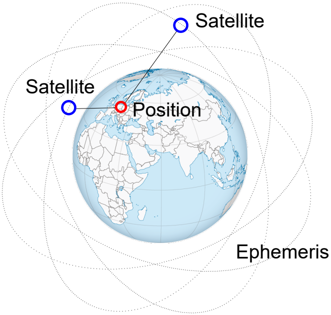
- New application emerge:
  - Autonomous driving.
  - ...
    - What about existing systems?



Introduction

- Global navigation satellite systems (GNSS) exists:
  - GPS (USA), GLONASS (Russia), GALILEO (Europe), Beidou (China).
- Signals from GNSS faces difficulties due to multipath, scattering or other effects.
- Obstacle penetration is impaired due to strong signal attenuation caused by distance.



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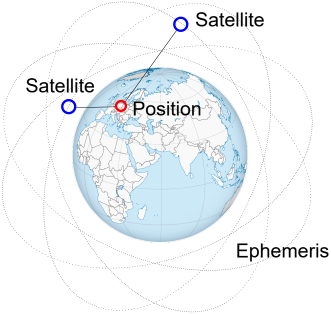
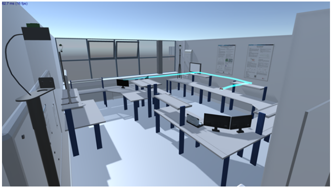
  - Solutions for indoor application required.



Introduction

- Manufactors for indoor positioning system / technologies:
  - Agilion, Decawave, Ekahau, Microchip, Nanotron, Ubisense,...
- Existing positioning systems require infrastructure, e.g. reference points.
  - Increases costs of positioning systems.
  - Position of the reference points is required.



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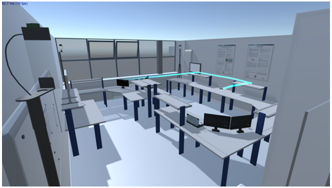

- Our goal: Reduce the number of reference points to decrease cost and to ease deployment.

Related Work

- SHARF: Combines acoustic and UWB-based message exchange.[1]

[1] Zubair et al.: *SHARF: A Single Beacon Hybrid Acoustic and RF Indoor Localization Scheme*

[2] Kumar et al.: *Indoor Localization System for 2D Measurement in European UWB Band with Single Reference Position*

[3] Leitinger et al.: *Cognitive indoor positioning and tracking using multipath channel information*

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- What are common approaches for indoor positioning using COTS products?

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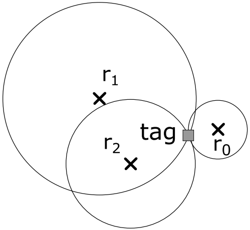
Approach

Lateration

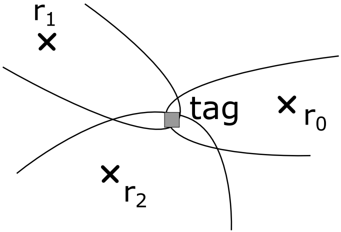
- Based on distance from reference points.



- Slow, no time synchronization is required.

Hyperbolic Lateration

- Based on difference of distances.



- Fast, time synchronization is required.

Approach

Lateration

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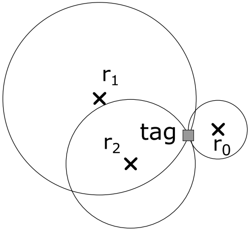

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Hyperbolic Lateration

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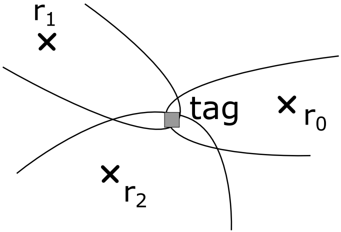
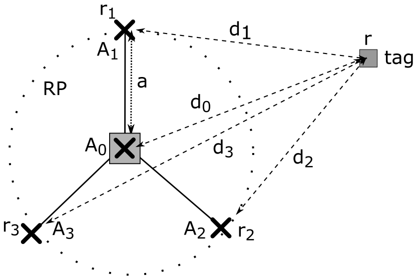


- Fast, time synchronization is required.
    - How can we reduce the number of reference points required for lateration or hyperbolic lateration?

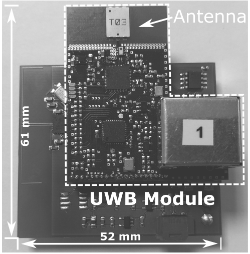
Approach

- Instead of using multiple reference points, we use multiple antennas in one entity.
- We place the antennas in the middle of a circle and create a single reference point.
- For lateration and hyperbolic lateration those antennas serves as *virtual reference points*.



Implementation

- We implemented the positioning system in our TinyTriSOS wireless sensor node.
- The DW1000 from Decawave performs ranging.
- Instead of multiple antennas, we use multiple TinyTriSOS nodes.

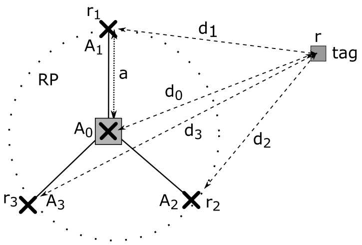


Implementation

- For hyperbolic lateration, the antennas needs to be synchronized.
- In our implementation synchronization is done via a common clock source.
- Position Calculation
  - For position estimation we employ a combination of Quasi-Linearizion and the Levenberg-Marquardt algorithm.
  - The Quasi-Linearization is a (approximative) closed form solution of the nonlinear positioning problem.
  - The Levenberg-Marquardt algorithm takes the solution of the Quasi-Linearization as a starting point and improves the solution.

Evaluation

- Evaluation was done in three steps.
  1. Theoretical Analysis
  2. Extensive simulations
  3. Evaluation



Theoretical Analysis

- A standard procedure for reference point based positioning systems is to investigate the geometry of the positioning problem[4].
  - Geometry describes the number and placement of reference points.
- Different metrics exists
  - (Geometric / Position) Dilution of Precision
  - Cramer-Rao Lower Bound
  - Error propagation
- All of them are very similar and we investigated the Cramer-Rao Lower Bound of the problem.

$$C_{\mathbf{r}} \geq \mathbf{E}\left[\left(\frac{\partial}{\partial r} \ln p\left(c|\mathbf{r}\right)\right)^2\right]^{-1}$$

[4] Zhao et al.: *2D geometrical performance for localization algorithms from 3D perspective*

Theoretical Analysis

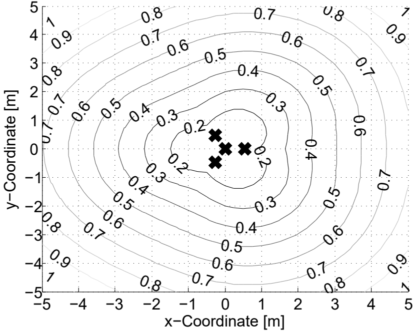
- The Cramer-Rao Lower Bound provides a lower bound for the variance of an estimator.
- Requires assumption of the type of noise along with the geometry of the problem.
  - For our analysis we assumed white Gaussian noise.
- The Cramer-Rao Lower Bound provides for each coordinate a matrix, therefore we calculate the trace of $\mathbf{C}_r$:

$$\Delta \mathbf{r}_c = \mathrm{tr}\left(C_{\mathbf{r}}\right) = \sum_{i=1}^{n} c_{\mathbf{r},ii}$$

- In this case the Geometric Dilution of Precision (GDOP) and the Cramer-Rao Lower Bound is identical.

Theoretical Analysis and Simulation

- For the simulation we define a target area of $10\,\text{m} \times 10\,\text{m}$ with a grid of $0.25\,\text{m}$.
- Three antennas are equally distributed with radii $a = \{0.1, 0.30, 0.55, 1.0\}$ m.



Simulation of the GDOP for $a = 0.55\,\text{m}$, $\sigma = 0.1\,\text{m}$ and four antennas.

Theoretical Analysis and Simulation

- We determine the positioning error ϵ as the Euclidean distance between true position $\mathbf{r}$ and estimate position $\hat{\mathbf{r}}$.

Simulation results for lateration with standard deviation $\sigma = 0.1\,\text{m}$, target area of $10\,\text{m} \times 10\,\text{m}$ and a grid of $0.25\,\text{m}$. All results in [m].

radius	0.10	0.30	0.55	1.00
mean GDOP	3.20	1.08	0.58	0.33
max GDOP	5.80	1.95	1.08	0.61
95 percentile ϵ	7.60	2.47	1.30	0.71

- With increasing radius *a* we expect a better accuracy.

Theoretical Analysis and Simulation

- We repeated the simulation for hyperbolic lateration.

Simulation results for hyperbolic lateration with standard deviation $\sigma = 0.1$ m, target area of 10 m $\times$ 10 m and a grid of 0.25 m. All results in [m].

radius	0.10	0.30	0.55	1.00
mean GDOP	> 10	> 10	> 10	3.68
max GDOP	> 10	> 10	> 10	> 10
95 percentile ϵ	> 10	> 10	> 10	> 10

Theoretical Analysis and Simulation

- We repeated the simulation for hyperbolic lateration.

Simulation results for hyperbolic lateration with standard deviation $\sigma = 0.1$ m, target area of 10 m $\times$ 10 m and a grid of 0.25 m. All results in [m].

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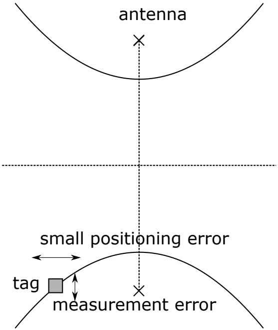
mean GDOP	> 10	> 10	> 10	3.68
max GDOP	> 10	> 10	> 10	> 10
95 percentile ϵ	> 10	> 10	> 10	> 10

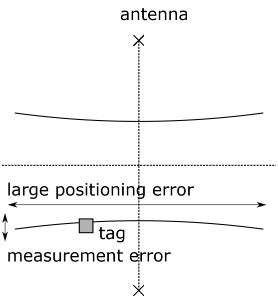
- Does not work.

Theoretical Analysis and Simulation

Good Geometry



Bad Geometry



Theoretical Analysis and Simulation

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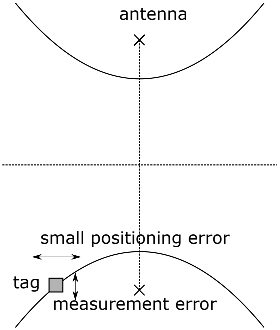

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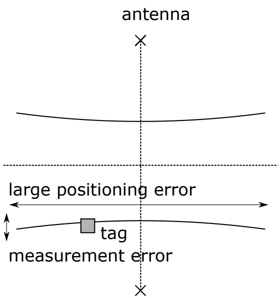
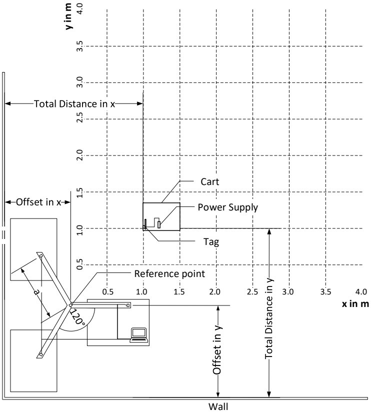


- In our case, we are always dealing with a bad geometry.

Evaluation Results

- The size of the target area is 4 m $\times$ 4 m with a grid of 0.5 m.
- For each position of the grid we tested three radii $a = \{0.1, 0.55, 1.0\}$ m.



Evaluation Results

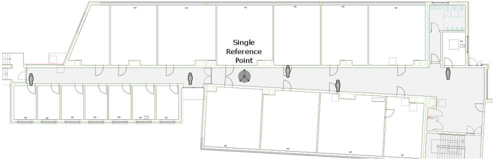
Simulation (S) and evaluation (E) results for the target area. All results in [m].

radius [m]	0.10	0.55	1.00
95 percentile lat. E	1.99	0.95	0.56
95 percentile lat. S	8.17	1.31	0.74
95 percentile hyp. lat. E	> 10	> 10	> 10
95 percentile hyp. lat. S	> 10	> 10	> 10

- Lateration works quite well.
- Hyperbolic lateration does not work.

Conclusion

- We have presented an UWB-based single reference point positioning system using multiple antennas.



- The antennas serve as additional virtual reference points for lateration and hyperbolic lateration.
- The positioning error in 95 percent of all measurements for lateration (in our setup) is below 0.56 m.