Landscape(T): A Robust and Low-cost Sensor Positioning System Using the Dual of Target Tracking

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Novelty and Contributions

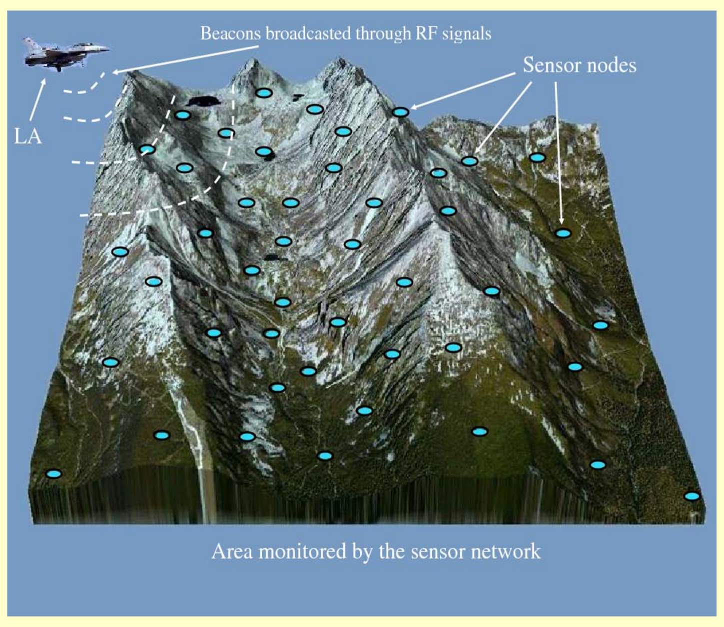
Localization from a NEW Perspective

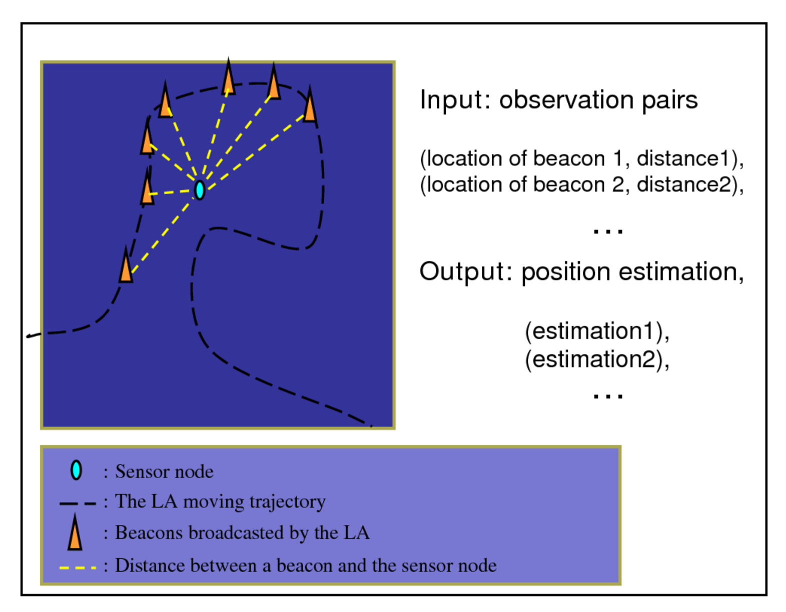
- Treat the sensor localization problem as the **dual of target tracking.**
- A moving location-aware location assistant (LA) periodically broadcasts beacons while it moves around the sensor field. Each sensor passively observes the beacons.
- Each sensor individually "tracks" its own position using a UKF (Unscented Kalman Filter) [1] based algorithm.

Advantages

- High accuracy, good scalability.
- ZERO sensor-to-sensor communication cost, low computation cost.
- Robust to node densities, network topologies, and ranging errors.
- Low cost; the cost of a single LA is amortized on each sensor node.

Methodology





Online dynamic state estimation:

- The state (3D position) of the ***i***th sensor at the ***n***th iteration is:

  $\mathbf{x}_i(n) = \{x_{i1}(n), x_{i2}(n), x_{i3}(n)\}$.
- For static sensors, the state and observation equations are:

  $\mathbf{x}_i(n+1) = \mathbf{x}_i(n) + \mathbf{w}_i(n)$,

  $\mathbf{y}_i(n) = ((\Delta x_{i1}(n))^2 + (\Delta x_{i2}(n))^2 + (\Delta x_{i3}(n))^2)^{1/2} + \mathbf{v}_i(n)$,

  where $\mathbf{y}_i(n)$ is the observed distance between the *n*th beacon and the *i*th sensor, $\Delta x_{i1}(n) = x^b_1(n) - x_{i1}(n)$, $\Delta x_{i2}(n) = x^b_2(n) - x_{i2}(n)$, $\Delta x_{i3}(n) = x^b_3(n) - x_{i3}(n)$, and $(x^b_1(n), x^b_2(n), x^b_3(n))$ is the 3D position of the *n*th beacon. $\mathbf{w}_i(n)$ and $\mathbf{v}_i(n)$ are noise sequences.

Unscented Kalman Filter (UKF) based algorithm:

- The UKF [1] embeds Unscented Transformation (UT) into Kalman Filter's prediction and update structure.
- The basic idea of UT is to represent the state distribution by a minimal set of carefully chosen sample points (sigma points).
- Best choice for our system: UKF is able to elegantly resolve the above nonlinear problem with higher accuracy and/or less computation cost than other KF variants or Bayesian techniques.

Landscape(T) vs. Landscape:

- In our previous work Landscape [2], beacons contain LA's locations and transmission powers only, the RSS (received signal strength) measurement is utilized.
- Landscape(T) adds a new observation equation:

  $\Delta \mathbf{t}_i(n) = (\mathbf{y}_i(n) - \mathbf{y}_i(n-1))/c + \mathbf{v}_{it}(n)$,

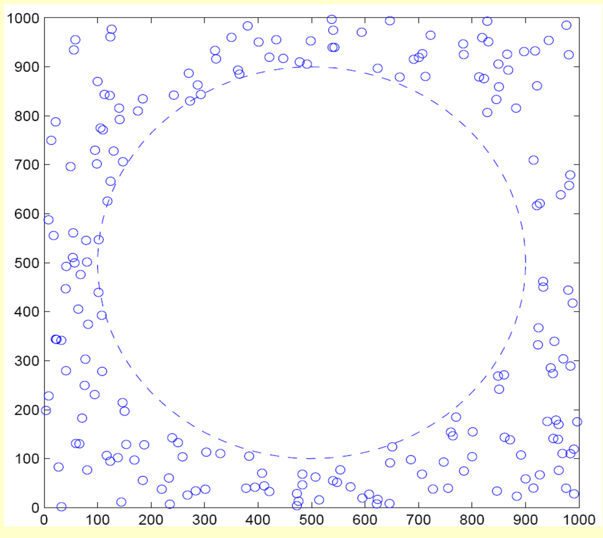
  where $\Delta t_i(n)$ the difference between the traveling times (from the LA to a sensor node) of two consecutive beacons. This TDoA (time difference of arrival) based new observation is delicately designed so that no time synchronization is needed.

Performance Evaluation

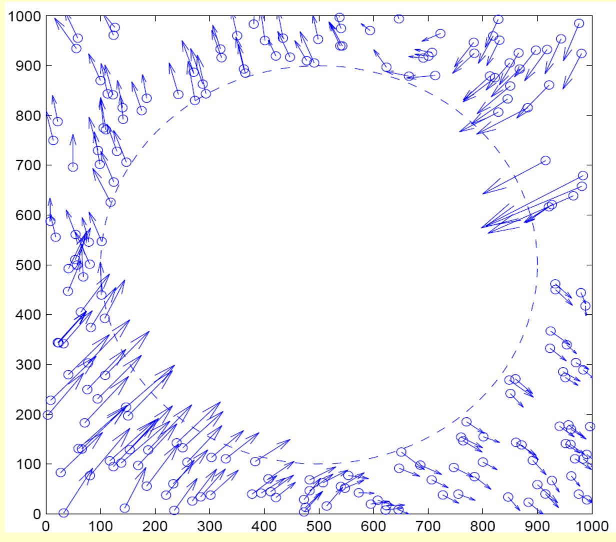
- Use MDS-MAP[3] (the state-of-the-art localization approach) as the reference.
- The result reported here is for a sensor network with irregular topology, in which sensors are deployed around a lake.

Landscape vs. MDS-MAP(P.R)

(Results for 10% range error)

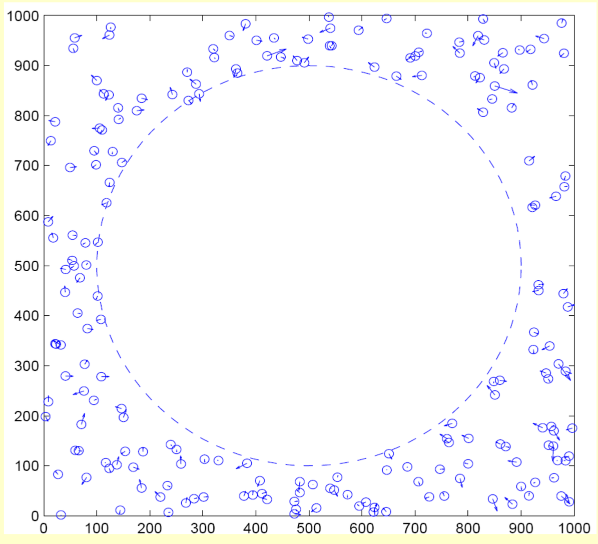


Original Map



Result of MDS-MAP(P,R)

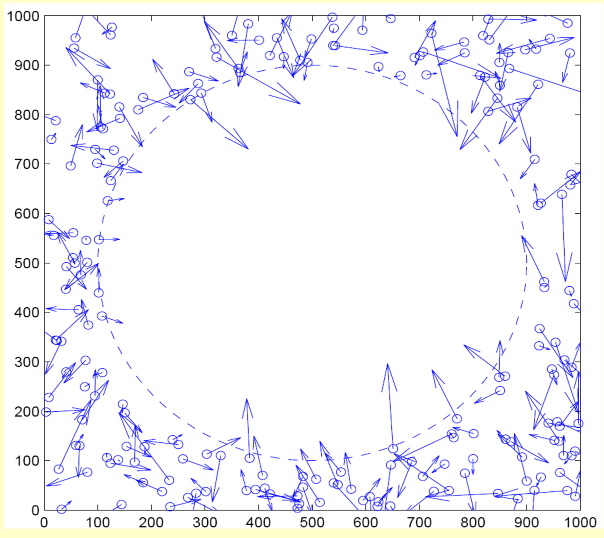
(connectivity = 32.970)



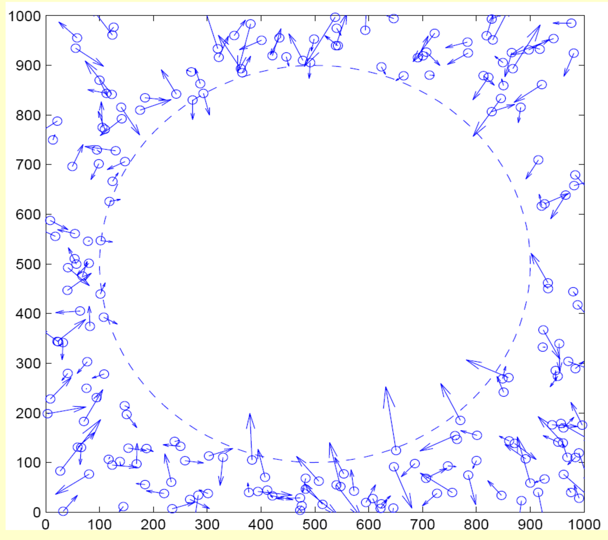
Result of Landscape

Landscape(T) vs. Landscape

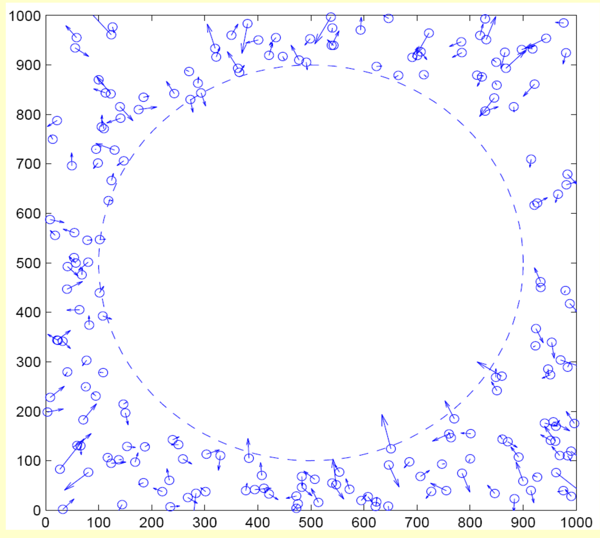
(Results for 60% range error)



Result of Landscape

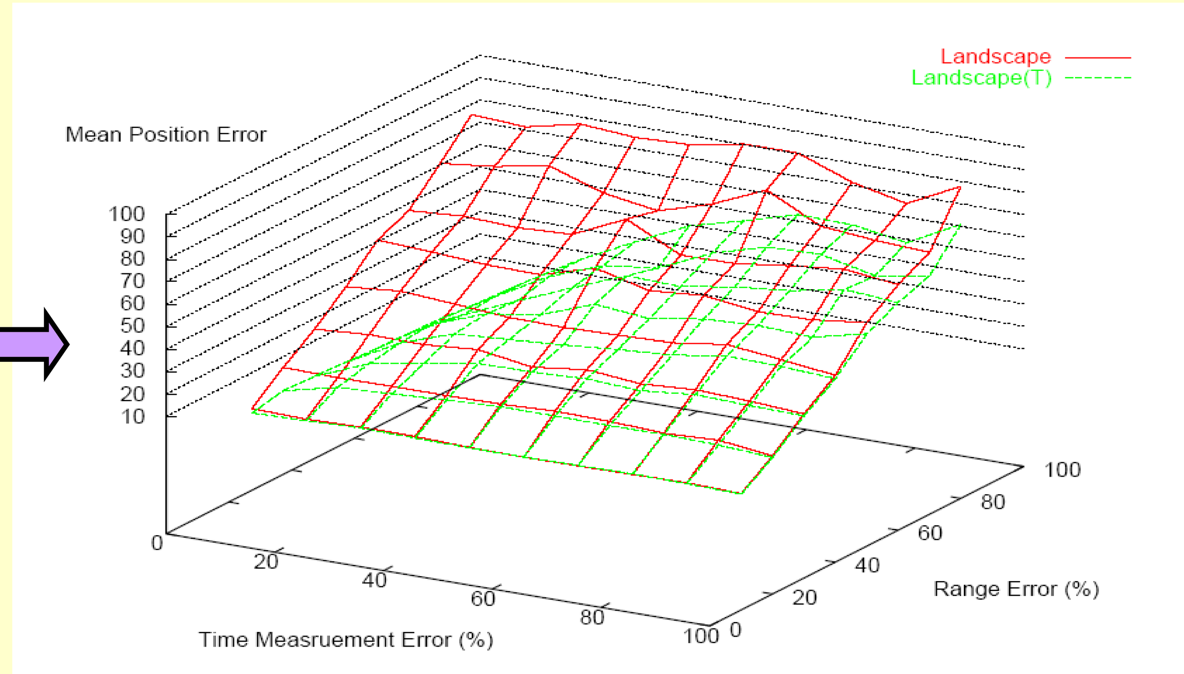


Result of Landscape(T) with 40% time measurement error



Result of Landscape(T) with 20% time measurement error

The improvement of Landscape(T) over Landscape



Summary

	Neighborhood-measurement-based localization methods	*Landscape*	*Landscape(T)*
Accuracy	**From low to high**, depending on algorithms as well as node densities. A high accuracy is usually at the cost of high computation cost.	**High.**	**Higher.**
Scalability	Depends on algorithms, **from low** (centralized) **to high** (distributed).	**High.**	**High.**
Computation cost	**From low to high**, depending on algorithms as well as node densities.	**Low.**	**Low.**
Communication cost (sensor-to-sensor)	**High to very high.**	**Zero**.	**Zero**.
Robustness to densities/topologies	**Weak**.	**Strong,** independent of densities/topologies.	**Strong,** independent of densities/topologies.
Robustness to range errors	**From weak to strong,** depending on algorithms.	**Strong.**	**Stronger.**
Ranging techniques	RSS, ToA, TDoA, or AoA	RSS	RSS + TDoA

References

[1] S. Julier and J. Uhlmann, "Unscented Filtering and Nonlinear Estimation", Proc. of the IEEE, Vol. 92, No. 3, March 2004

[2] L. Zhang et al., "A Novel Distributed Sensor Positioning System Using the Dual of Target Tracking", online technical report, http://www.cs.iusb.edu/~liqzhang/Liqiang_Landscape.pdf (A short version published in IEEE WiMob'05).

[3] Y. Shang et al., "Localization from Connectivity in Sensor Networks", IEEE Transactions on Parallel and Distributed Systems, Vol. 15, No. 11, November 2004.