A UNIFIED APPROACH FOR HYBRID SOURCE LOCALIZATION BASED ON RANGES AND VIDEO

PÓLO DO I.S.T

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Abstract

We present a **hybrid** method for **single-source localization in wireless sensor networks**, fusing noisy **range measurements** with **angular information** extracted from video. We develop and test a hybrid localization algorithm which surpasses the limitations of previous fusing approaches found in the literature. The proposed method (**FLORIS**) is based on a **nonconvex least-squares joint formulation**, for which a **tight convex relaxation** is applied to obtain a **semidefinite program**.

1. Introduction

- The "where am I" problem is a key issue in technology.
- GPS is not available neither indoors nor in underwater environments; these are challenging scenarios due to strong multi-path propagation, difraction and interference leading to poor localization accuracy.
- The key to overcome these issues lies on exploring hybrid schemes. We fuse distances and angular information to localize a target in a wireless sensor network.
- Attempts to fuse these two types of information have been presented, but impose severe limitations.

2. Problem Formulation: Hybrid Source Localization (FLORIS)

Let $x \in \mathbb{R}^n$ be the target position to be estimated based on m known reference points (anchors) $a_i \in \mathbb{R}^n$, $i = 1, \dots, m$.

- Anchors in set $\mathcal{R}$ provide range measurements to the source: $d_i = \|x - a_i\| + w_i$, w_i is a noise term.
- Anchors in set $\mathcal{T}$ measure bearings u_i, a perturbed versor centered around the true direction $\frac{x - a_i}{\|x - a_i\|}$.

We propose estimating the source position by minimizing the joint least-squares cost function:

$$f(x) = \sum_{i \in \mathcal{R}} D^2(x, C_i) + \sum_{i \in \mathcal{T}} D^2(x, L_i) \,, \quad (1)$$

with $D^2(x, C_i) = (\|x - a_i\| - d_i)^2$ and

$D^2(x, L_i) = (x - a_i)^T (I_n - u_i u_i^T)(x - a_i)$.

We attempt to balance the distances of the source position estimate relative to:

- the circles C_i centered at the wireless anchors with radii d_i;
- the lines L_i originating at the visual anchors with orientation u_i.

An alternative parametrization for minimizing (1), inspired in [1] is:

$$\begin{aligned} &\underset{x, y_i, \theta_i, t_i}{\text{minimize}} \sum_{i=1}^{m} \|x - y_i\|^2 \\ &\text{subject to} \quad y_i = a_i + d_i \theta_i, \quad \|\theta_i\| = 1, \quad i \in R \\ &\qquad\qquad\quad y_i = a_i + u_i t_i, \quad t_i \in \mathbb{R}^+, \quad i \in T \end{aligned} \quad (2)$$

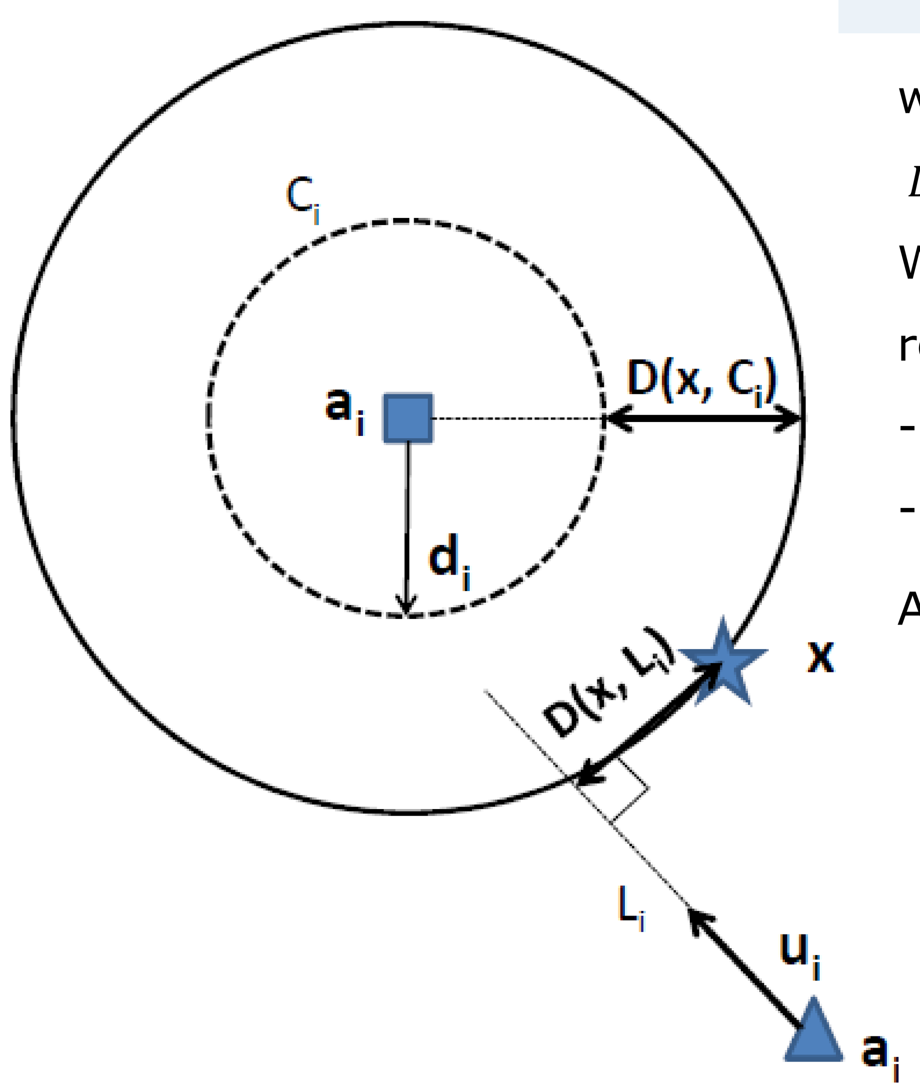


Fig. 1. Geometric representation of terms in the joint cost function (1)

Given the constellation y_i, $x = \frac{1}{m}\sum_i y_i$ lies at the center of mass. Making $y = a + \mathbf{R}\begin{bmatrix}\boldsymbol{\theta} \\ \boldsymbol{t}\end{bmatrix}$, problem (2) is written as:

FLORIS formulation:

Relaxed SDP

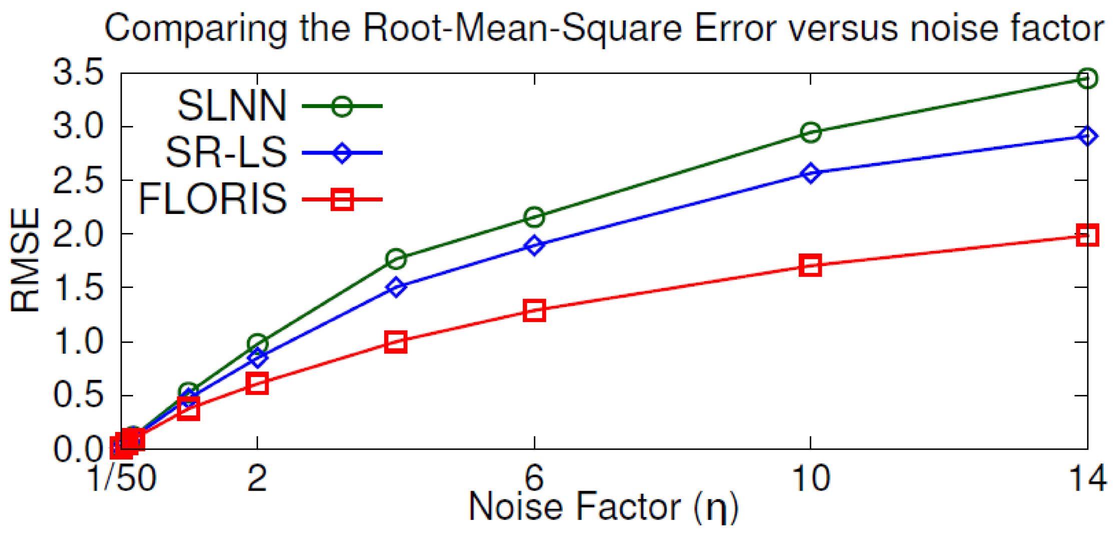
$$\begin{aligned} &\underset{W}{\text{minimize}} \ tr\left(\begin{bmatrix} R^*JR & R^*Ja \\ a^*JR & a^*Ja \end{bmatrix} \underbrace{\begin{bmatrix}\boldsymbol{\theta} \\ \boldsymbol{t} \\ \mathbf{1}\end{bmatrix}\begin{bmatrix}\boldsymbol{\theta}^T & \boldsymbol{t}^T & 1\end{bmatrix}}_{W}\right) \\ &\text{subject to} \quad \boldsymbol{W} \succeq 0 \qquad \boldsymbol{W}_{i,nm+1} \geq 0, \ i \in T, \qquad \cancel{rank(\boldsymbol{W}) = 1} \\ &\qquad\qquad\quad tr(\boldsymbol{W}_{i,i}) = \mathbf{1}, i \in R \qquad \boldsymbol{W}_{nm+1,nm+1} = 1 \end{aligned} \quad (3)$$

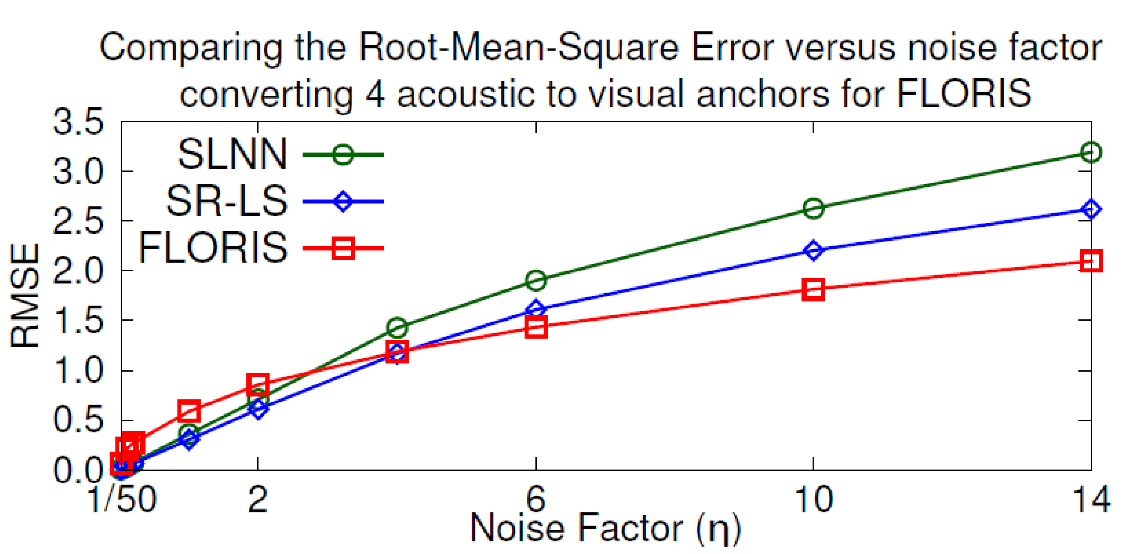
- Vectors θ and t can be obtained by SVD factorization.
- The relaxation performed is tight (frequency of $rank(\boldsymbol{W}) = 1$ is high), hence the optimal solution is frequently found.

3. Results – 3D source localization performance

Simulation results:

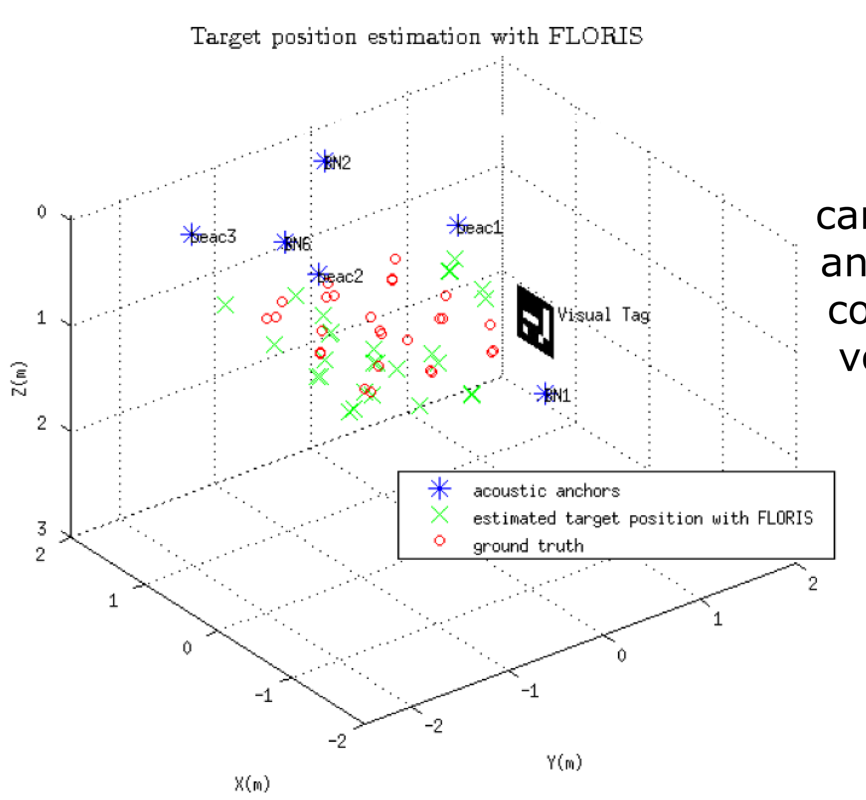
- Randomly generated networks of 6 acoustic and 4 visual anchors.
- Source randomly positioned.
- Noise factor (η) is a scaling factor relative to an established baseline scenario reflecting the precision found in the experimental setup.
- 1000 Monte Carlo runs for each noise factor.





Experimental results:

- Experimental set-up, consisting on acoustic anchors and augmented reality tags as visual anchors.



The target, a video camera rigidly coupled to an acoustic source node, could roam in a covered volume of about 50m³.

	SR-LS [2]	SLNN [1]	FLORIS
RMSE (m)	0.1738	0.1973	0.1609

Table 1. 3D source localization performance comparison, for a data set obtained in the experimental set-up

4. Conclusions and future work

- **FLORIS** is a **new** approach for centralized **localization** based on **nonlinear least squares** relying on a **tight SDP relaxation** that provides an **efficient solution** method using a generic convex solver.
- In numerical results FLORIS achieves **higher accuracy than state-of-the-art** methods, specially for **high noise** scenarios. In a **real indoor deployment** FLORIS shows **better accuracy** than the benchmarks.

References

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[2] A. Beck and P. Stoica, "Exact and Approximate Solutions of Source Localization Problems," IEEE Transactions on Signal Processing, vol. 56, no. 5, pp. 1770–1778, May 2008.

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