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AN EFFICIENT TARGET LOCALIZATION ESTIMATOR FROM BISTATIC RANGE AND TDOA MEASUREMENTS IN MULTISTATIC RADAR

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Abstract

Problem Description

- Target localization problem in multistatic passive radar

Method

- Algebraic closed-form method
- Based on two-stage WLS estimator
- Using the hybrid BR and TDOA measurements

Advantage

- Provide a better target localization accuracy than using BR alone
- Be able to reach CRLB accuracy

Application and Model

Application

(locating a target, such as the helicopter in Fig.1)

- Ground air defense
- Low airspace surveillance

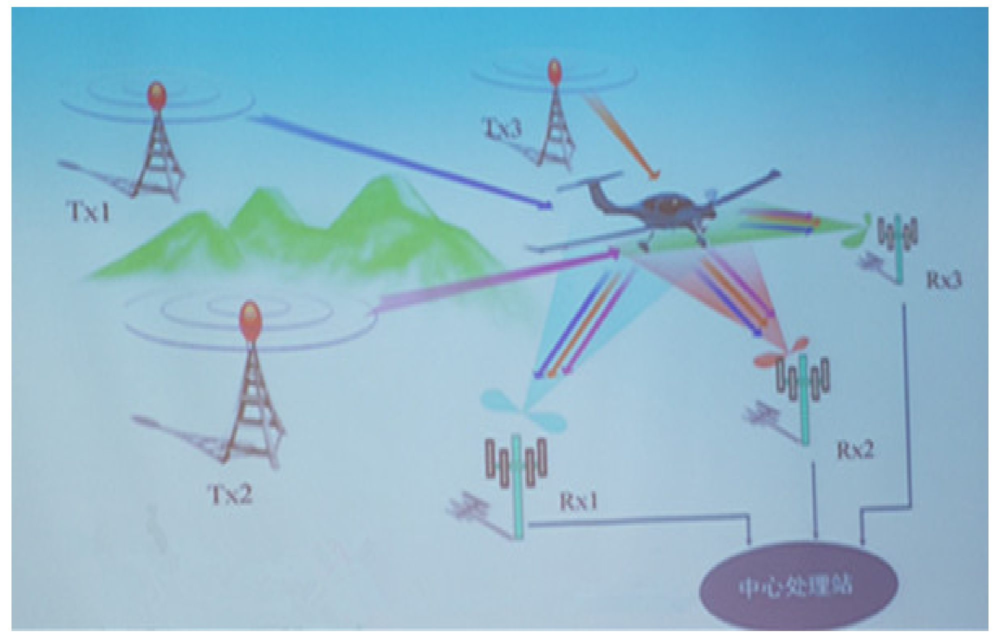

Fig.1. Target passive localization scenario based on external illuminator

Data Model

- 3D space
- M transmitters, $\boldsymbol{t}_i = \left[x_i^t, y_i^t, z_i^t\right]^{\mathrm{T}}$
- N receivers, $\boldsymbol{s}_j = \left[x_j^s, y_j^s, z_j^s\right]^{\mathrm{T}}$
- A single target, $\boldsymbol{u} = \left[x, y, z\right]^{\mathrm{T}}$

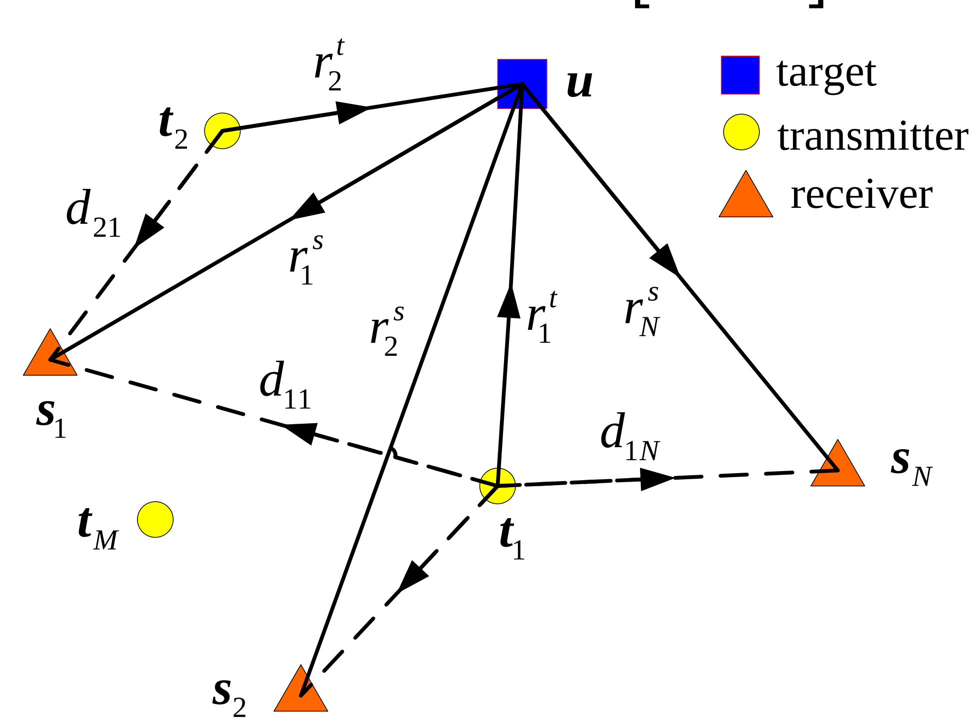

Fig.2. Target localization geometry

BR Measurement

- BR: bistatic range

$$r_{ij} = r_{ij}^o + \Delta r_{ij} = r_i^t + r_j^s - d_{ij} + \Delta r_{ij}$$

- MN BR Measurements

$$\boldsymbol{r} = \left[\boldsymbol{r}_1^{\mathrm{T}}, \boldsymbol{r}_2^{\mathrm{T}}, \cdots, \boldsymbol{r}_N^{\mathrm{T}}\right]^{\mathrm{T}} = \boldsymbol{r}^o + \Delta\boldsymbol{r}$$

$$\boldsymbol{r}_j = \left[r_{1j}, r_{2j}, \cdots, r_{Mj}\right]^{\mathrm{T}} = \boldsymbol{r}_j^o + \Delta\boldsymbol{r}_j$$

TDOA Measurement

- TDOA: time difference of arrival

$$\overline{r}_{j1} = \overline{r}_{j1}^o + \Delta\overline{r}_{j1} = r_j^s - r_1^s + \Delta\overline{r}_{j1}$$

- N TDOA Measurements

$$\overline{\boldsymbol{r}} = \left[\overline{r}_{21}, \overline{r}_{31}, \cdots, \overline{r}_{N1}\right]^T = \overline{\boldsymbol{r}}^o + \Delta\overline{\boldsymbol{r}}$$

Method Derivation

First Stage

- BR positioning equation

$$2r_i^t \Delta r_{ij} \simeq r_{ij}^2 + 2r_{ij}d_{ij} + 2(\boldsymbol{s}_j - \boldsymbol{t}_i)^{\mathrm{T}}\boldsymbol{s}_j - 2(\boldsymbol{s}_j - \boldsymbol{t}_i)^{\mathrm{T}}\boldsymbol{u} - 2(r_{ij} + d_{ij})r_j^s$$

- TDOA positioning equation

$$2r_j^s \Delta\overline{r}_{j1} \simeq \overline{r}_{j1}^2 + \boldsymbol{s}_1^{\mathrm{T}}\boldsymbol{s}_1 - \boldsymbol{s}_j^{\mathrm{T}}\boldsymbol{s}_j - 2(\boldsymbol{s}_1 - \boldsymbol{s}_j)^{\mathrm{T}}\boldsymbol{u} + 2\overline{r}_{j1}r_1^s$$

- Matrix form equation

$$\boldsymbol{B}_1\Delta\boldsymbol{m} = \boldsymbol{h}_1 - \boldsymbol{G}_1\boldsymbol{\varphi}^o, \boldsymbol{\varphi}^o = \left[\boldsymbol{u}^T, r_1^s, r_2^s, \cdots, r_N^s\right]^{\mathrm{T}}$$

- WLS solution $\boldsymbol{\varphi} = (\boldsymbol{G}_1^{\mathrm{T}}\boldsymbol{W}_1\boldsymbol{G}_1)^{-1}\boldsymbol{G}_1^{\mathrm{T}}\boldsymbol{W}_1\boldsymbol{h}_1$

Second Stage

- First stage solution

$$\boldsymbol{\varphi} = \left[\hat{\boldsymbol{u}}^T, \hat{r}_1^s, \hat{r}_2^s, \cdots, \hat{r}_N^s\right]^{\mathrm{T}} = \boldsymbol{\varphi}^o + \Delta\boldsymbol{\varphi}$$

- Dependency relationship

$$\Delta r_j^s \simeq \hat{r}_j^s - \left\|\hat{\boldsymbol{u}} - \boldsymbol{s}_j\right\| + \boldsymbol{\rho}_{\hat{\boldsymbol{u}},\boldsymbol{s}_j}^{\mathrm{T}}\Delta\boldsymbol{u}$$

- Matrix form equation

$$\boldsymbol{B}_2\Delta\boldsymbol{\varphi} = \boldsymbol{h}_2 - \boldsymbol{G}_2\Delta\boldsymbol{u}$$

- WLS solution

$$\Delta\hat{\boldsymbol{u}} = (\boldsymbol{G}_2^{\mathrm{T}}\boldsymbol{W}_2\boldsymbol{G}_2)^{-1}\boldsymbol{G}_2^{\mathrm{T}}\boldsymbol{W}_2\boldsymbol{h}_2,\ \tilde{\boldsymbol{u}} = \hat{\boldsymbol{u}} - \Delta\hat{\boldsymbol{u}}$$

Simulation Results

Simulation Conditions

- 5 transmitters, 5 receivers, 1 target
- $\boldsymbol{Q_r} = \delta_{\mathrm{d}}^2\boldsymbol{I}_{MN}$, $\boldsymbol{Q}_{\overline{r}} = \delta_{\mathrm{d}}^2\boldsymbol{I}_{N-1}$, $\boldsymbol{Q_m} = \mathrm{diag}(\boldsymbol{Q_r}, \boldsymbol{Q}_{\overline{r}})$
- 5000 ensemble runs

Table.1. Average accuracy improvement, N=5

Improvment	M=2	M=3	M=4	M=5
RMSE (dB)	3.80	1.37	0.96	0.56
CRLB (dB)	1.41	0.97	0.81	0.49

Simulation 1

- Be illustrated in Fig.3 and Table.1
- Performance of proposed method is best, due to introduction of TDOA
- Accuracy improvement is affected by the number of transmitters

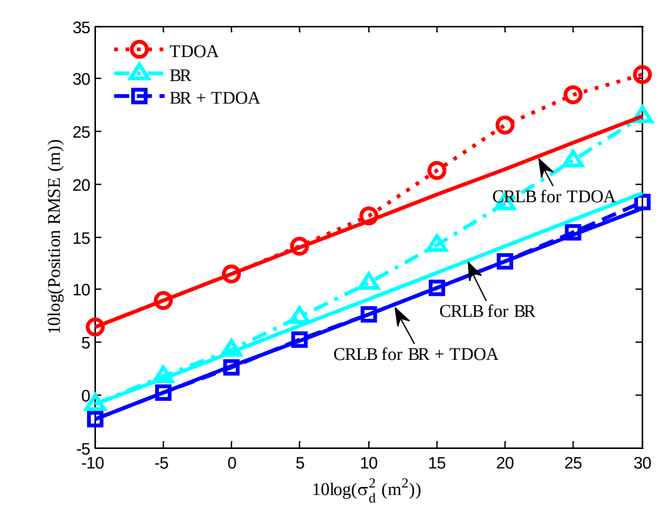

Fig.3. M=2, N=5

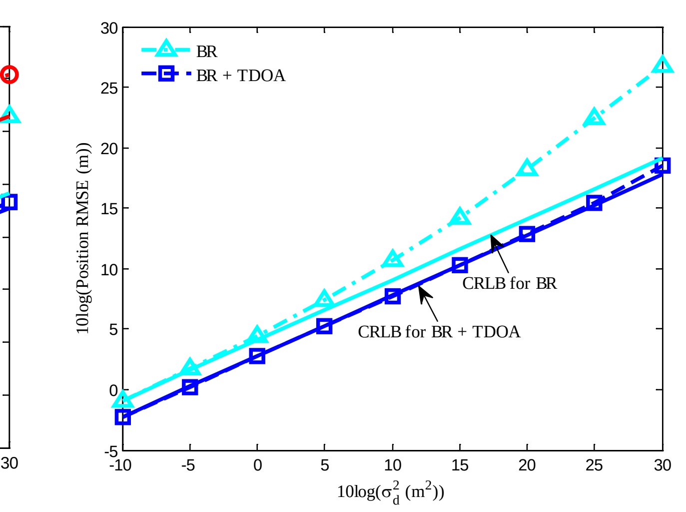

Fig.4. M=2, N=4

Simulation 2

- Be reported in Fig.4
- The hybrid method outperforms the BR-based method, even though TDOA-based method fails to work

Conclusion

(1) This paper proposed a target localization algorithm using hybrid BR and TDOA measurements

(2) It can provide a better location accuracy than BR-based method

(3) It's able to attain CRLB bound, under small Gaussian measurement noise.