Localization of GNSS Signals Jammers Using TDOA Measurements

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Outlines

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- Statistical Apparatus
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Introduction

- GNSS technology is becoming very ubiquitous.
- GNSS has brought succour to humanity.
- The socio-economic benefits of GNSS are enormous.

Unfortunately, despite the lofty benefits of GNSS, the technology is being threatened by malicious and unintentional interference (e.g., man-made: jammers or nature-made: space weather effects).

Jammers and their Proliferation

The proliferation of jammers in the markets is becoming very worrisome.

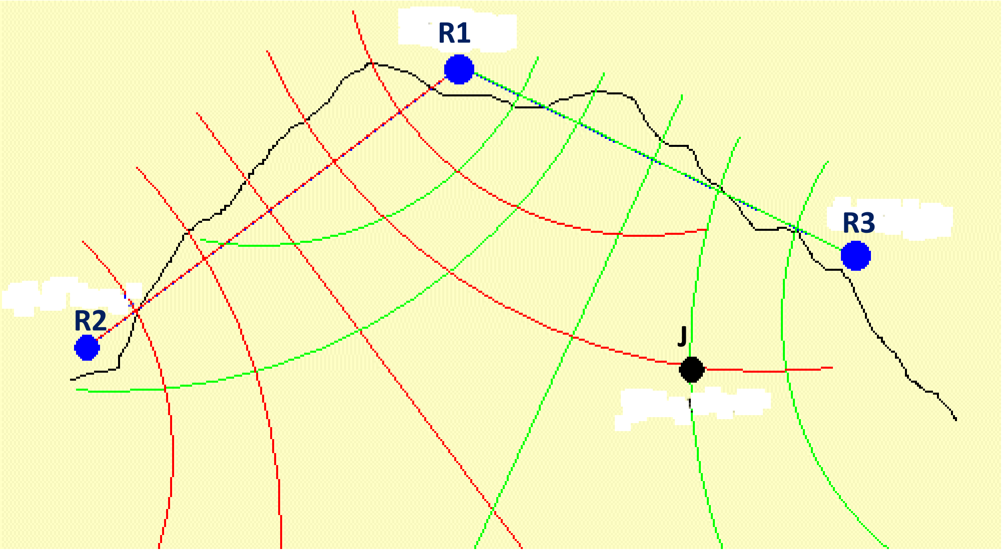
Jammers are devices with the capabilities of partially or totally obscuring the navigation signals that are being received by GNSS receivers that are within their vicinity.

Although, many nations have developed strict legal penalties for intentional use of jammers to disrupt GNSS signals, however, the techniques for identifying their presence within the GNSS users' vicinity before havoc have not been well developed.

Hyperbolic Navigation-TDOA Approach

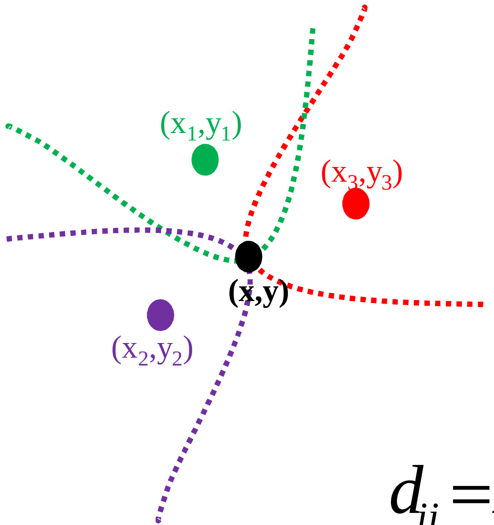
Time difference of arrival (TDOA) of signals from a network of at least three GNSS receivers as a method of determining the location of a jammer.

1 receiver serves as a reference, while the other 2 produce the hyperbolic lines whose lines of intersection define the location of the jammer.



TDOA Location Configuration 1/2

3 receivers (x_i, y_i) and 1 jammer (x,y), $i = 1,2,3$



The range from the jammer to the *ith* receiver can be expressed as:

$$D_i = \sqrt{(x - x_i)^2 - (y - y_i)^2}$$

For the *ith* and *jth* pair of receivers, the range difference is:

$$d_{ij} = D_i - D_j = \sqrt{(x - x_i)^2 - (y - y_i)^2} - \sqrt{(x - x_j)^2 - (y - y_j)^2} \qquad (1)$$

Defining t_{ij} as the TDOA of signals between the *ith* and *jth* receivers

$d_{ij} = ct_{ij}$ $\quad$ c= speed of light $\quad$ Hence,

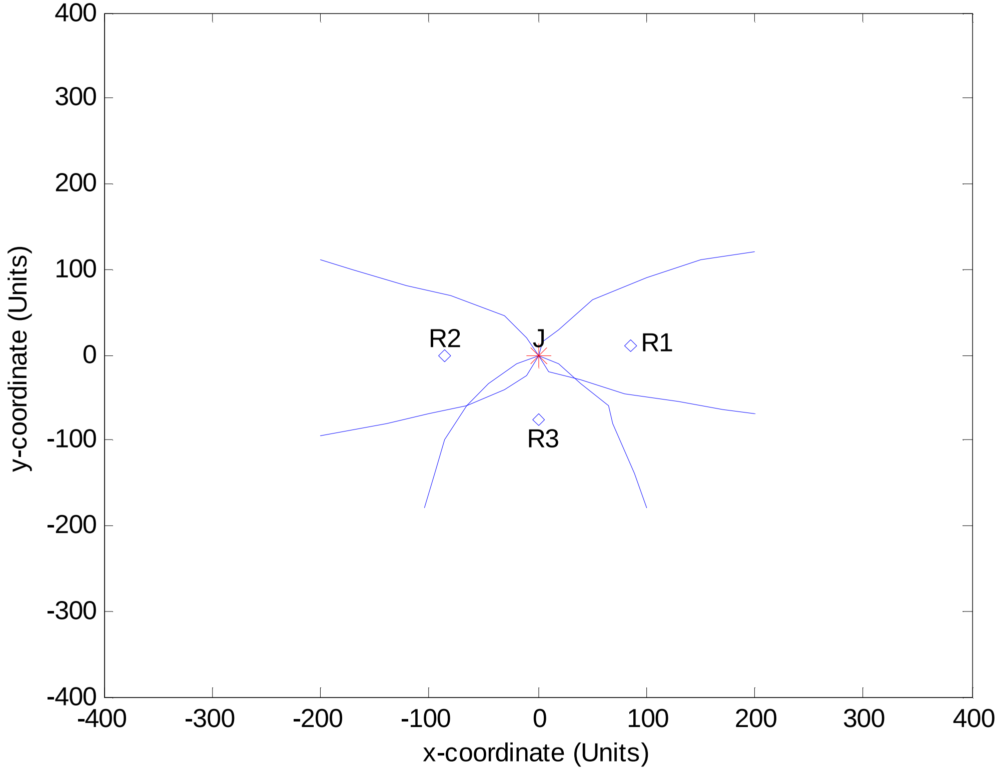
$$\sqrt{(x - x_i)^2 - (y - y_i)^2} - \sqrt{(x - x_j)^2 - (y - y_j)^2} = ct_{ij}$$

TDOA Location Configuration 2/2

Eq. (1) is a set of non-linear equations that can be solved with Taylor's series expansion with a good initial guess. It can be modified in form of norms as: $d_{ij} = \left\| \mathbf{X} - \mathbf{X_i} \right\| + \left\| \mathbf{X} - \mathbf{X_1} \right\| - \left\| \mathbf{X_i} - \mathbf{X_1} \right\| + \mathbf{n_i}$

$\mathbf{n_i}$= zero Gaussian distributed measurement error

Simulation:
J(0,0), R1(100,10);
R2(-100,0); R3(0,-90)
Units



Statistical Apparatus

- Cramer Rao Lower Bound (CRLB)

CRLB Concept

CRLB is commonly used to set a lower bound on an estimator's mean square error (MSE) and it states that the variance of any unbiased estimator is at least as high as the inverse of its Fisher Information matrix. Therefore, the CRLB sets a benchmark against which the performance of an unbiased estimation is compared. The CRLB can also be used to rule-out infeasible estimators.

Let, $d = [d_{21}, d_{31}]^T \qquad n = [n_2, n_3]^T \qquad g(x) = [g_2(x), g_3(x)]$

$$d_{i1} = \|\mathbf{X} - \mathbf{X_i}\| + \|\mathbf{X} - \mathbf{X_1}\| - \|\mathbf{X_i} - \mathbf{X_1}\| + \mathbf{n_i}$$

$$i = 2,3$$

$$g_i(x) = \|\mathbf{X} - \mathbf{X_i}\| + \|\mathbf{X} - \mathbf{X_1}\| - \|\mathbf{X_i} - \mathbf{X_1}\|$$

Fisher Information Matrix

For a condition where the additive measurement errors have zero mean and are independent of the range difference observation, as well as the jammer coordinate, **X**. Thus, the probability density function of the measured range difference conditioned on the jammer location **X** can be expressed as:

$$P(d/X) = \frac{e\left(-\frac{1}{2}[d-g(x)]^T Q_n^{-1}[d-g(x)]\right)}{\sqrt{(2\pi)^3 \det(Q_n)}}$$

Q_n= covariance of matrix *n*

$$Q_n = \begin{bmatrix} \sigma_2^2 & 0 \\ 0 & \sigma_3^2 \end{bmatrix}$$

The Fisher Information Matrix, FI is:

$$FI(x) = \left[\frac{\partial g(x)}{\partial x}\right]^T Q_n^{-1} \left[\frac{\partial g(x)}{\partial x}\right]$$

Fisher Information Matrix

$\left[\frac{\partial g(x)}{\partial x}\right]$ is a 2x2 Jacobian matrix

$$\left[\frac{\partial g(x)}{\partial x}\right] = \begin{bmatrix} \frac{\partial g_2(x)}{\partial x} & \frac{\partial g_2(x)}{\partial y} \\ \frac{\partial g_3(x)}{\partial x} & \frac{\partial g_3(x)}{\partial y} \end{bmatrix}$$

$$\left[\frac{\partial g(x)}{\partial x}\right] = \begin{bmatrix} \frac{x-x_2}{\|\mathbf{X}-\mathbf{X}_2\|} + \frac{x-x_1}{\|\mathbf{X}-\mathbf{X}_1\|} & \frac{y-y_2}{\|\mathbf{X}-\mathbf{X}_2\|} + \frac{y-y_1}{\|\mathbf{X}-\mathbf{X}_1\|} \\ \frac{x-x_3}{\|\mathbf{X}-\mathbf{X}_3\|} + \frac{x-x_1}{\|\mathbf{X}-\mathbf{X}_1\|} & \frac{y-y_3}{\|\mathbf{X}-\mathbf{X}_3\|} + \frac{y-y_1}{\|\mathbf{X}-\mathbf{X}_1\|} \end{bmatrix}$$

Optimization Techniques

- Kalman Filter: A non-linear technique

Meta-heuristic Algorithms

- Particle Swarm Optimization (PSO)
- Genetic Algorithm (GA)
- Ant Colony Optimization (ACO)

Particle Swarm Optimization (PSO)

- PSO: Population-based algorithm that drew inspiration from the social behaviour of flock of birds and school of fishes.
- The potential solutions are particles, flying through the problem space by following the current optimum particle.
- It begins by creating an initial particle with an assigned velocity. The objective function is evaluated at each particle location. The choice of a new velocity will be based on current velocity.

Genetic Algorithm (GA)

- This is based on natural selection process of the biological evolution concept. It is relevant when solving constrained and unconstrained optimization problems.

- Individuals= the parents which populate a new generation. Two parents combine to produce children, and random changes can occur to parents.

Ant Colony Optimization (ACO)

- ACO: Population-based algorithm that drew inspiration from the complex social behaviour of ants. It is commonly used in path optimization.

Curbing Jamming by Legal Framework

Local authorities would be the most effective at discouraging jamming

- Protecting GPS for public safety would be the priority
  - Local airports and aircraft
  - Emergency vehicle use
  - Vehicle tracking

- Heavy fines would discourage GPS jamming
  - Adequate regulations/enforcement

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Thank You

for your attention!!!

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