

GNSS cloud-data processing technique for jamming detection and localization

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Research Background

Ref. [1] Samson, J. (2014), *An Introduction to Interference in GNSS-bands*, Presentation at ENC2014

- ❖ Various jamming sources can interfere with the satellite signals at the receiver
 - ❖ Many low-cost jammers were developed and circulated on the market
- We need the technique for detection and localization of weak jamming signals

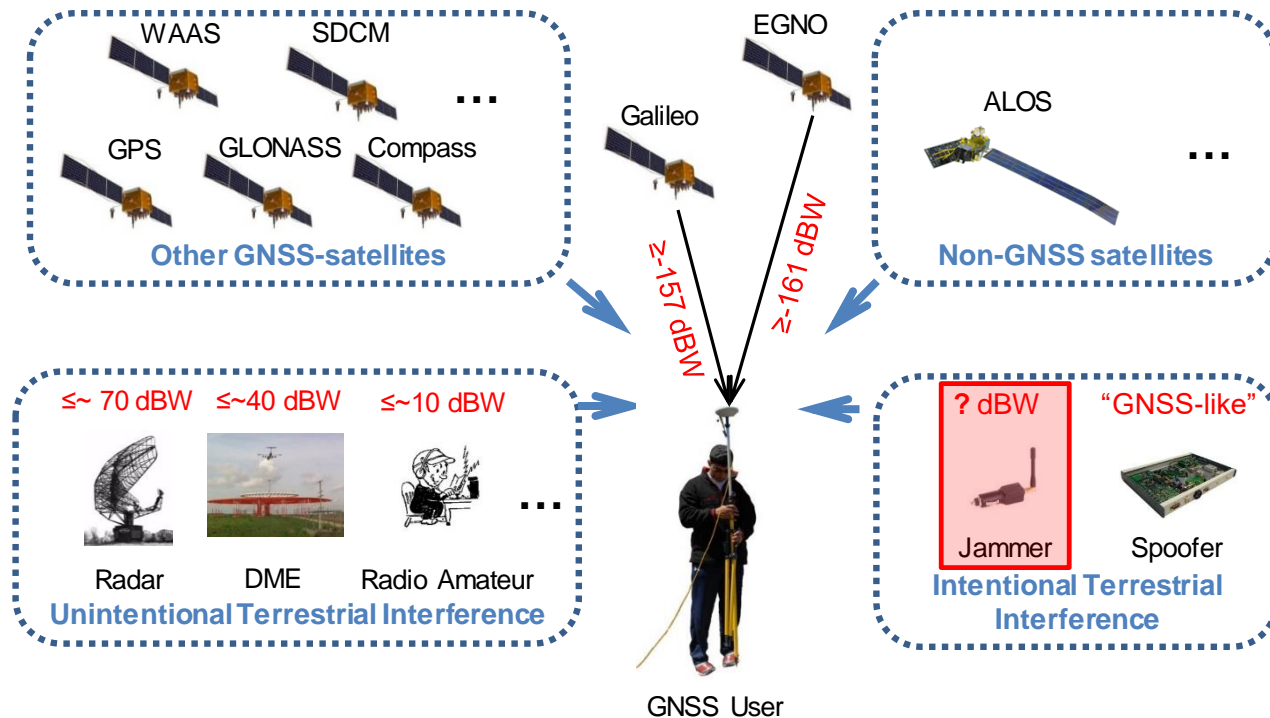


Figure: RF Transmissions in GNSS-bands [1]

❖ Other Researches (about using a large number of GNSS receivers)

- **Ref. [2], [3]** : estimate the location of the interference source through a number of independent monitoring stations consisting of low-cost antennas and front-end modules.

- **[2]** Lindstrom, J., Akos, D. M., Isoz, O., and Junered, M. (2007), GNSS Interference Detection and Localization using a Network of Low-cost Front-End Modules, Proceedings of the 20th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2007), pp.1165-1172
- **[3]** Isoz, O., Balaei, A. T., and Akos, D. M. (2010), Interference Detection and Localization in the GPS L1 Band, Proceedings of the 2010 International Technical Meeting of The Institute of Navigation, pp.925-929

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- **Ref. [2], [3]** : estimate the location of the interference source through a number of independent monitoring stations consisting of low-cost antennas and front-end modules.
- **Ref. [4], [5]** : identify the constant envelope (CE) type jamming signal and estimate the jammer's location by using jamming-to-noise (J/N) observations and location information acquired from a large number of smartphones.

- **[4]** Scott, L. (2010), *J911: Fast Jammer Detection and Location Using Cell-Phone Crowd-Sourcings*, GPS World 21, no. 11.
- **[5]** Scott, L. (2011), *J911: The Case for Fast Jammer Detection and Location Using Crowdsourcing Approaches*, Proceedings of the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2011), pp.1931-1940

❖ Other Researches (about using a large number of GNSS receivers)

- **Ref. [2], [3]** : estimate the location of the interference source through a number of independent monitoring stations consisting of low-cost antennas and front-end modules.
- **Ref. [4], [5]** : identify the constant envelope (CE) type jamming signal and estimate the jammer's location by using jamming-to-noise (J/N) observations and location information acquired from a large number of smartphones.
- **Ref. [6]** : uses carrier-to-noise density(C/N_0) and AGC information obtained from many smartphones to distinguish between the jamming and the spoofing signals and estimate the jammer position.

- **[6]** Strizic, L., Akos, D. M., and Lo, S. (2018), *Crowdsourcing GNSS Jammer Detection and Localization*, Proceedings of the 2018 International Technical Meeting of The Institute of Navigation, pp.626-641

Research Introduction

❖ Jamming Scenario of a Weak Jammer

- Jammer transmitting weak jamming signals is located between a number of low-cost GNSS receivers distributed in a dense density over a large area
- Types of jamming signals : CWI, MSI, BLWI, Pulse, Chirp

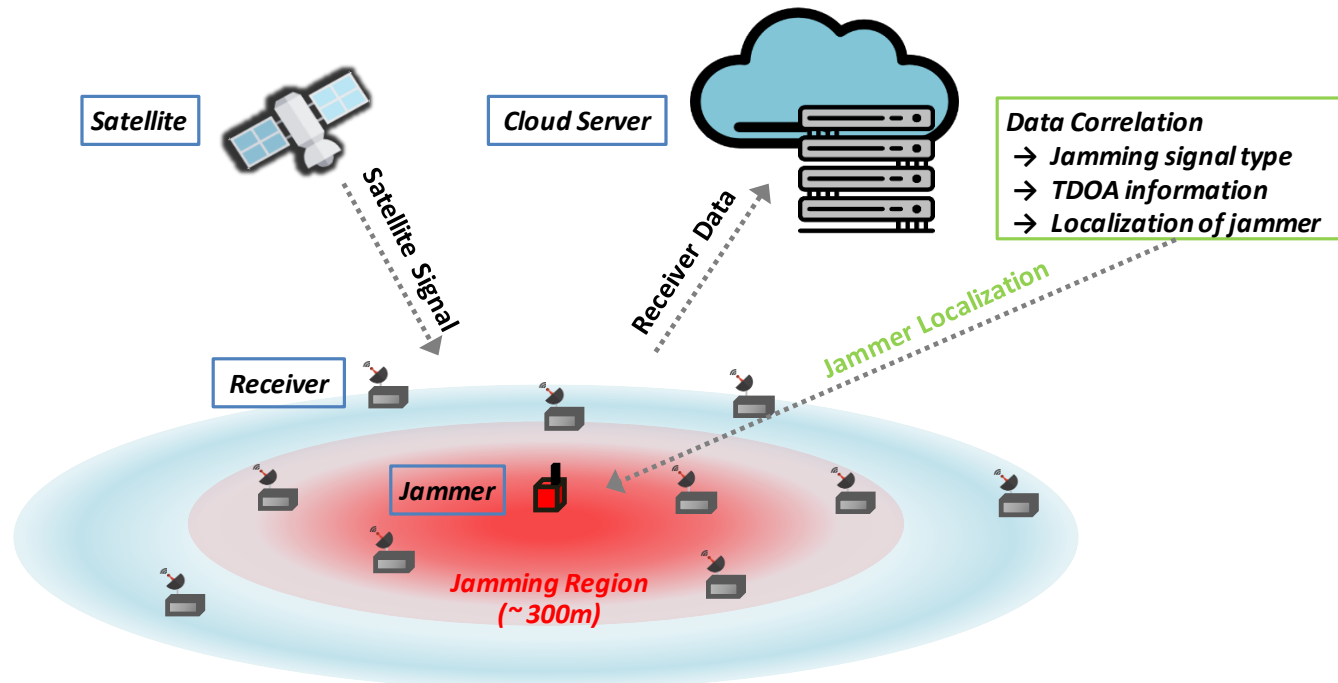


Figure: Schematic depiction of jamming scenario and processing procedure of the receiver data

❖ Time-Frequency Correlation Method

- The frequency value with the largest amplitude of the jamming signal will be different from the center frequency of the satellite signal in the time-frequency domain 2-D image
→ **Presence and type of jamming signal can be determined by monitoring 2-D images**
- 2-D image from a receiver close to the jammer has a higher amplitude than a far-away receiver
→ **Jammer position can be estimated roughly by using the 2-D image correlation**
- When the two IF signals are correlated in the time domain, the correlation of the jamming signal has a different form of peak depending on the jamming signal type
→ **Presence and type of jamming signal can be determined by analyzing correlation form**
- The correlation peak of the jamming signal contains the TDOA information
→ **Jammer position can be estimated by using the NLSE method**

Time-Frequency Correlation Method

① 2-D Image Correlation in the Time-Frequency Domain

- 2-D image can be obtained by applying FFT to the IF signals over time
- n sample length is corresponding to T_S
- The frequency bin is expressed in other colors according to the magnitude of the amplitude

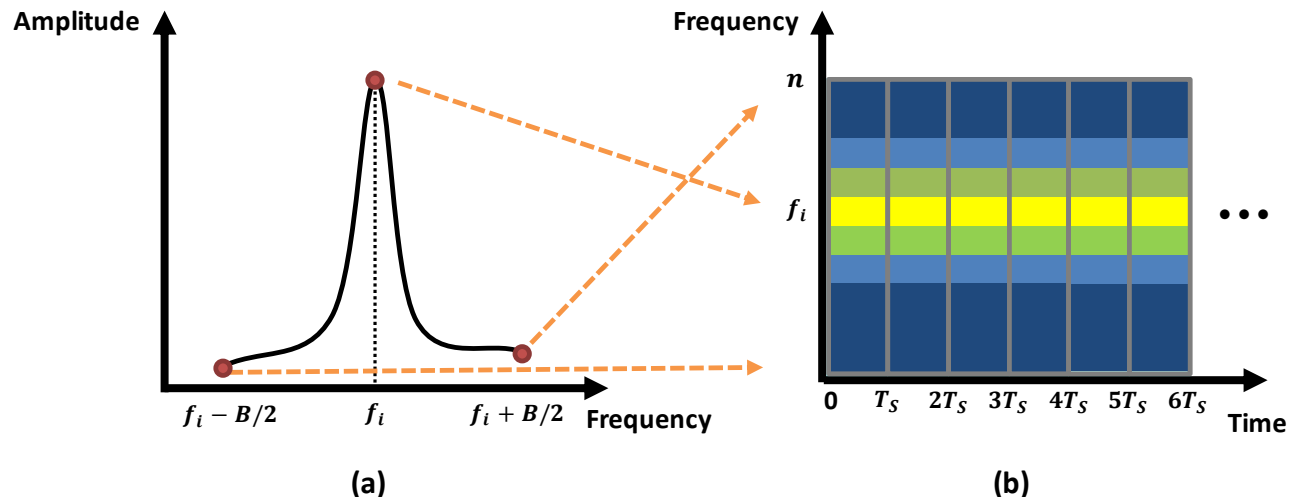
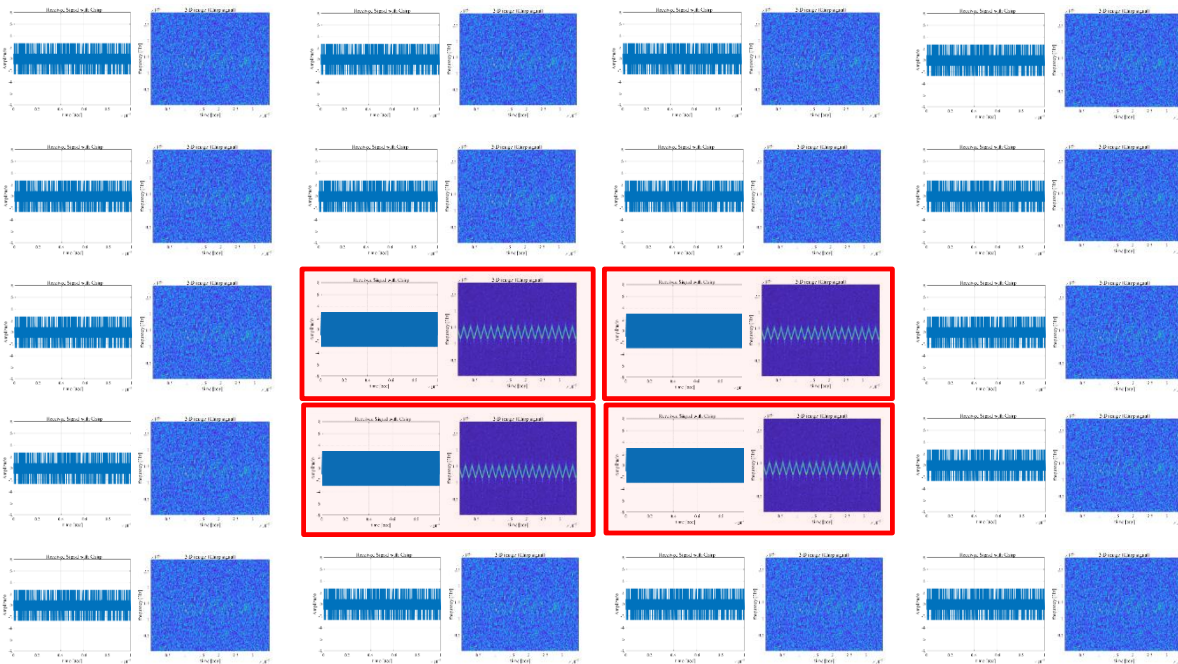


Figure: Method of generating a 2-D image in the time-frequency domain
(a) FFT result of n sample length IF signal at any one time **(b)** Generated 2-D image

① 2-D Image Correlation in the Time-Frequency Domain

- Jamming detection scenario using 2-D image correlation with cloud-data computing



Cloud Server



Detecting the same 2-D image pattern through the 2-D image correlation

→ Discriminate the presence and the type of jamming signal

② Signal Correlation in the Time Domain

- Correlation between the two IF signals received at two different receivers
- Satellite signal and jamming signal have different time delays ($\tau_{S,A}$, $\tau_{S,B}$, $\tau_{J,A}$, $\tau_{J,B}$)

$$\begin{aligned}
 R(\tau) &= r_A * r_B \\
 &= \{S(t - \tau_{S,A}) + J(t - \tau_{J,A}) + \eta_A\} \\
 &\quad * \{S(t - \tau_{S,B}) + J(t - \tau_{J,B}) + \eta_B\}
 \end{aligned}$$

where, r_A, r_B ... received signal for receiver A, B

$\tau_{S,A}, \tau_{S,B}$... time delay of satellite signal for receiver A, B

$\tau_{J,A}, \tau_{J,B}$... time delay of jamming signal for receiver A, B

η_A, η_B ... noise component for receiver A, B

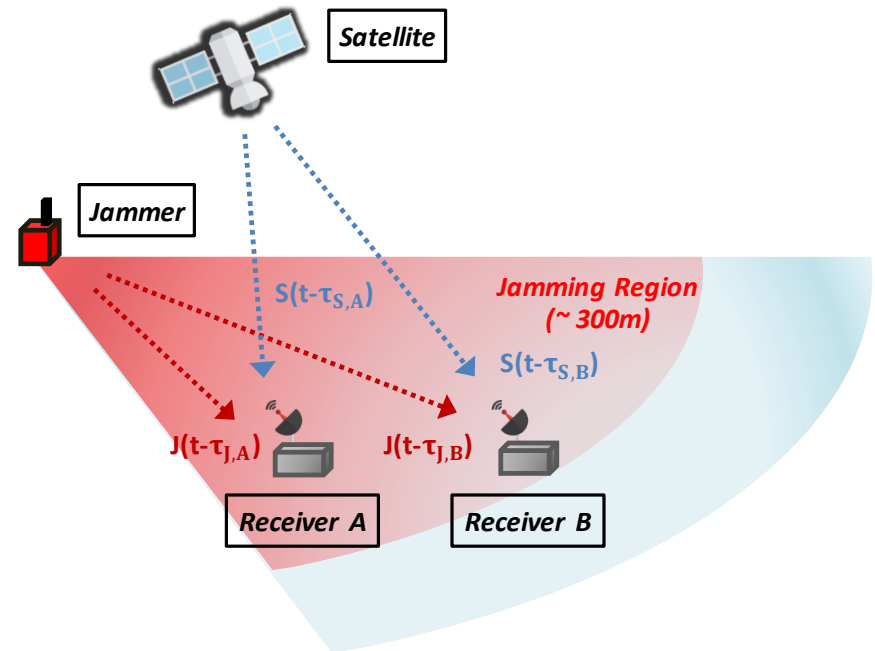


Figure: Jamming scenario for two receivers in another location

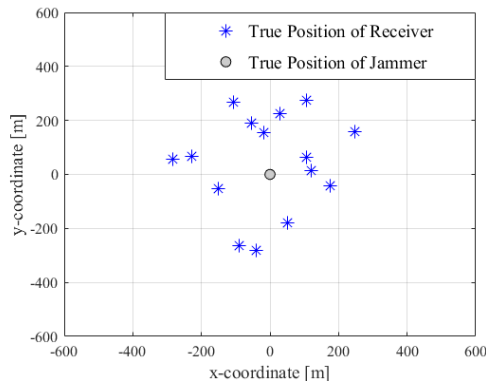
Simulation And Results

❖ Simulation parameter

- $J_{msi}(t) = \sqrt{2P_i}C(t) \cos(2\pi f_i t + \theta_i)$
 - IF frequency : 1.406 MHz
 - code : PRN #1, no data
- $J_{blwi}(t) = \sqrt{2P_i}n(t) \cos(2\pi f_i t + \theta_i)$
 - IF frequency : 1.406 MHz
 - noise bandwidth : 0.2 MHz
- $J_{chirp}(t) = \sqrt{2P_i} \cos\left(2\pi\left(f_i + \frac{k}{2}t\right)t + \theta\right)$
 - IF frequency : 1.406 MHz
 - sweep range : 0.1 MHz
 - sweep time : $100^{-6} s$
- $J_{pulse}(t) = \sqrt{2P_i}rectpuls(t, d, r) \cos(2\pi f_i t + \theta_i)$
 - IF frequency : 1.406 MHz
 - duration : $10^{-6} s$
 - repetition : 3000 Hz
- $J_{cwi}(t) = \sqrt{2P_i} \cos(2\pi f_i t + \theta_i)$
 - IF frequency : 1.406 MHz

❖ Simulation parameter

- Free Space Propagation Loss
 - $L_p = L \left(\frac{4\pi R}{\lambda} \right)^2 [W] \rightarrow L_p = L_{dB} + 20 \log_{10}(4\pi) - 20 \log_{10}(R/\lambda)$
 - $J/N = 0dB$ at 200m from Jammer
- Signal processing parameter
 - *Sampling rate* = 28.57 MHz
 - *integration time* = 1 ms
 - *2-D image generation* = 285 FFT samples per time index
- Arrangement of receivers



❖ Matched Spectrum interference(MSI)

- $$J_{msi}(t) = \sqrt{2P_i}C(t) \cos(2\pi f_i t + \theta_i)$$

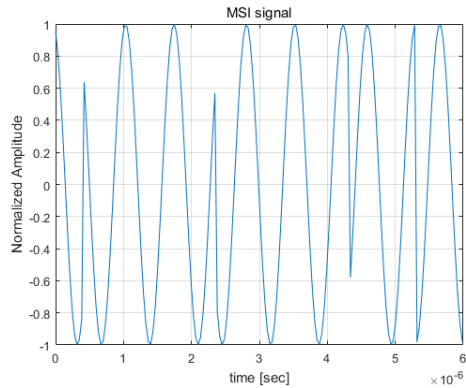


Fig 1 : MSI signal over time

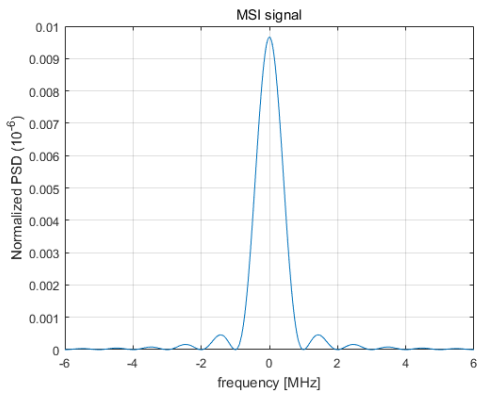


Fig 2 : FFT result of MSI signal

correlation

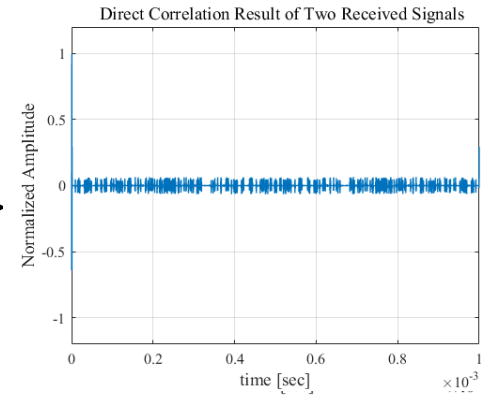


Fig 3 : signal correlation

Over time

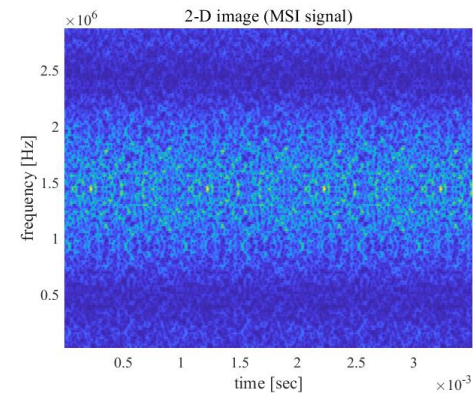


Fig 4 : 2-D image

❖ Matched Spectrum interference(MSI)

$$J_{msi}(t) = \sqrt{2P_i}C(t) \cos(2\pi f_i t + \theta_i) + noise$$

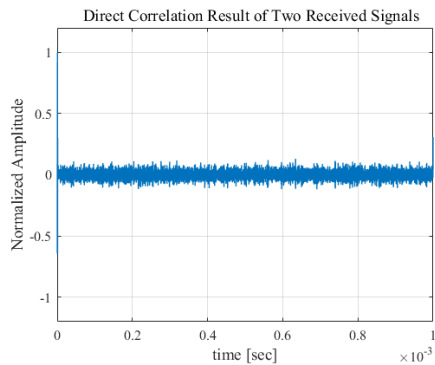


Fig 1 : 1ms correlation

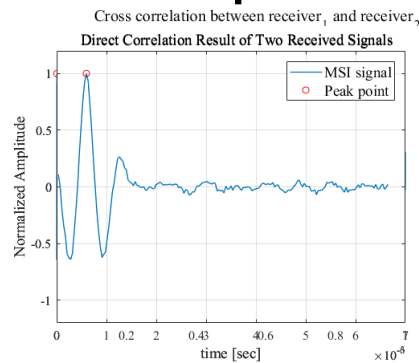


Fig 2 : 1μs correlation

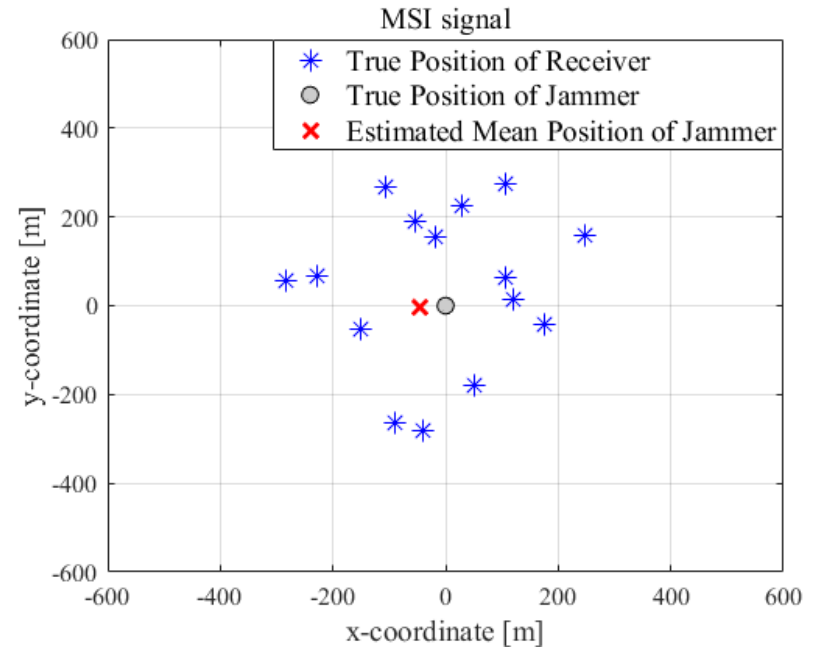


Fig 3 : the result of estimated position

	X coordinate	Y coordinate
Mean position error	-45.44 [m]	-4.291 [m]

❖ Continuous Wave Interference(BLWI)

- $$J_{blwi}(t) = \sqrt{2P_i}n(t) \cos(2\pi f_i t + \theta_i)$$

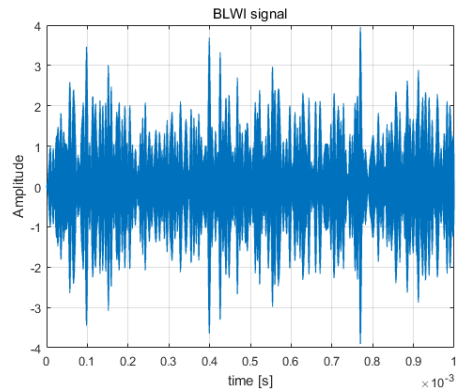


Fig 1 : BLWI signal over time

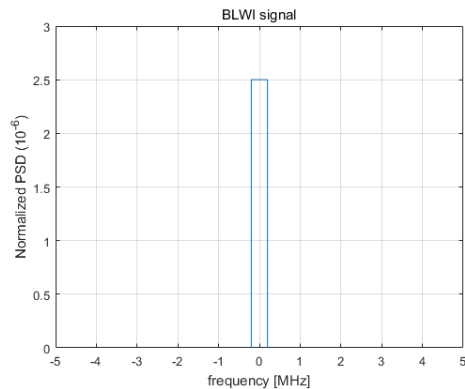


Fig 2 : FFT result of BLWI signal

correlation

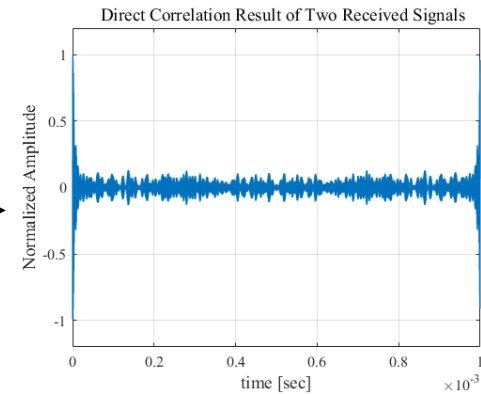


Fig 3 : signal correlation

Over time

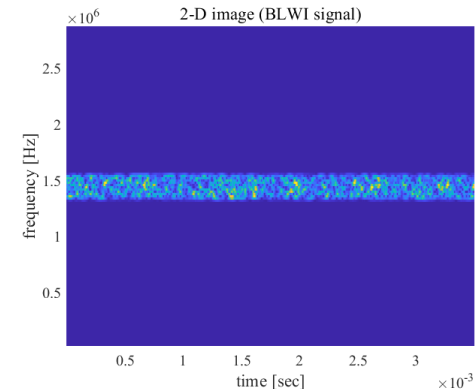


Fig 4 : 2-D image

❖ Band-Limited White Interference(BLWI)

$$J_{blwi}(t) = \sqrt{2P_i}n(t) \cos(2\pi f_i t + \theta_i) + noise$$

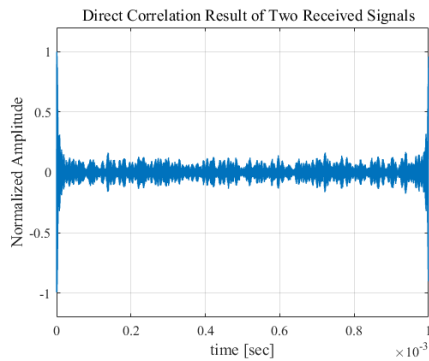


Fig 1 : 1ms correlation

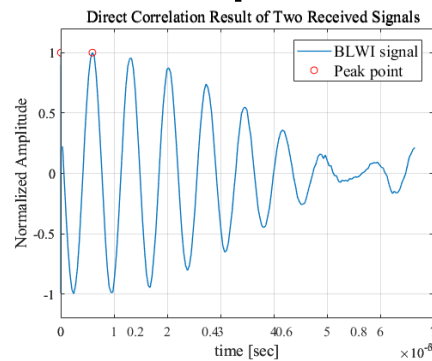


Fig 2 : 1µs correlation

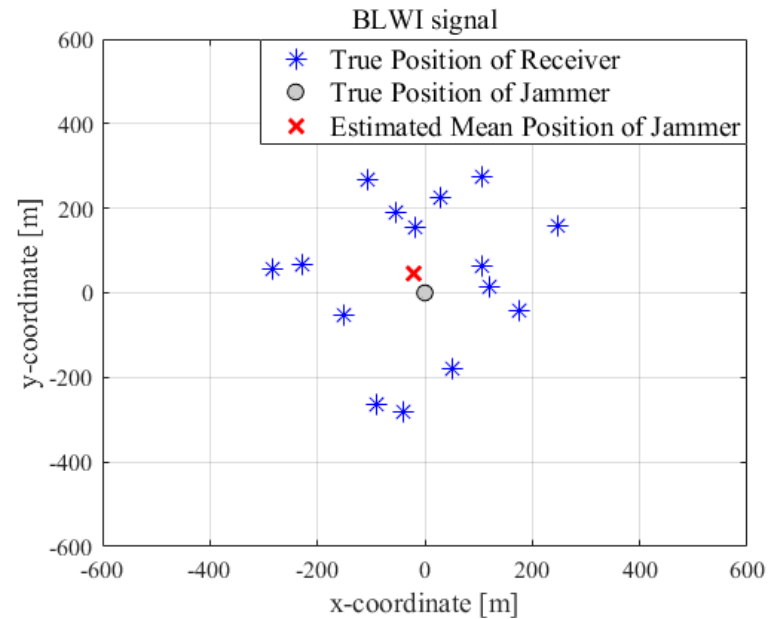


Fig 3 : the result of estimated position

	X coordinate	Y coordinate
Mean position error	21.13 [m]	45.05 [m]

❖ Chirp jammer

- $$J_{chirp}(t) = \sqrt{2P_i} \cos\left(2\pi\left(f_i + \frac{k}{2}t\right)t + \theta\right)$$

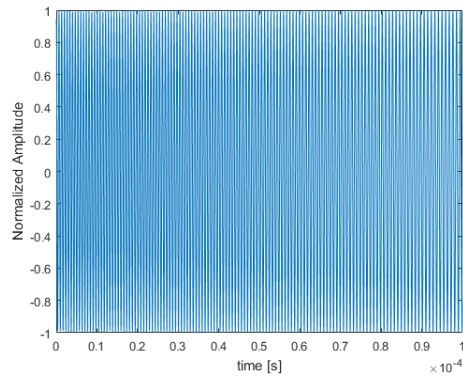


Fig 1 : Chirp signal over time

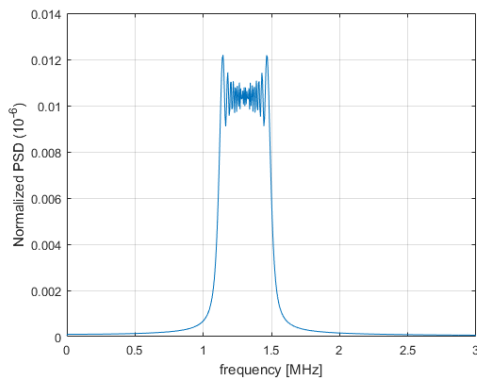


Fig 2 : FFT result of Chirp signal

correlation →

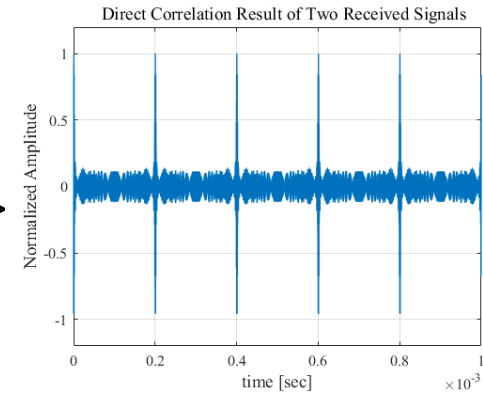


Fig 3 : signal correlation

Over time →

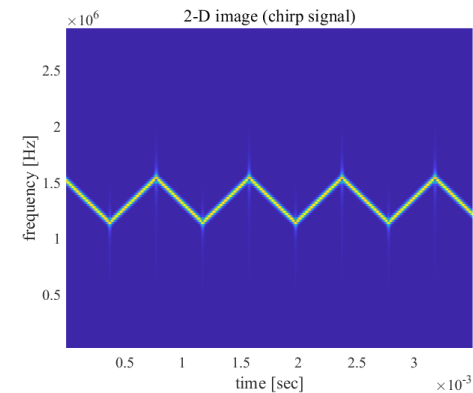


Fig 4 : 2-D image

❖ Chirp jammer

- $$J_{chirp}(t) = \sqrt{2P_i} \cos\left(2\pi\left(f_i + \frac{k}{2}t\right)t + \theta\right) + noise$$

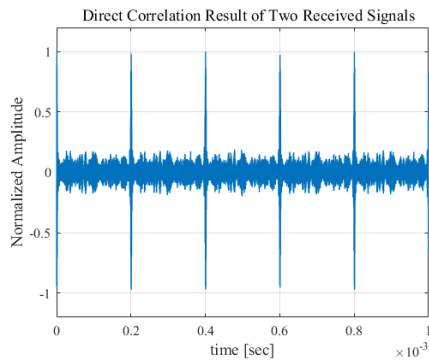


Fig 1 : 1ms correlation

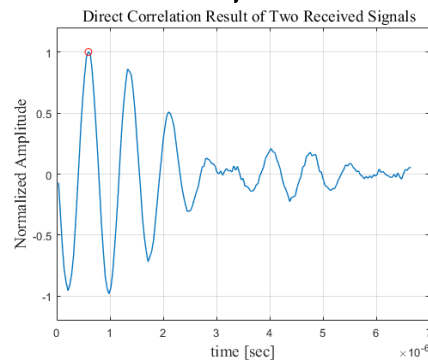


Fig 2 : 1µs correlation

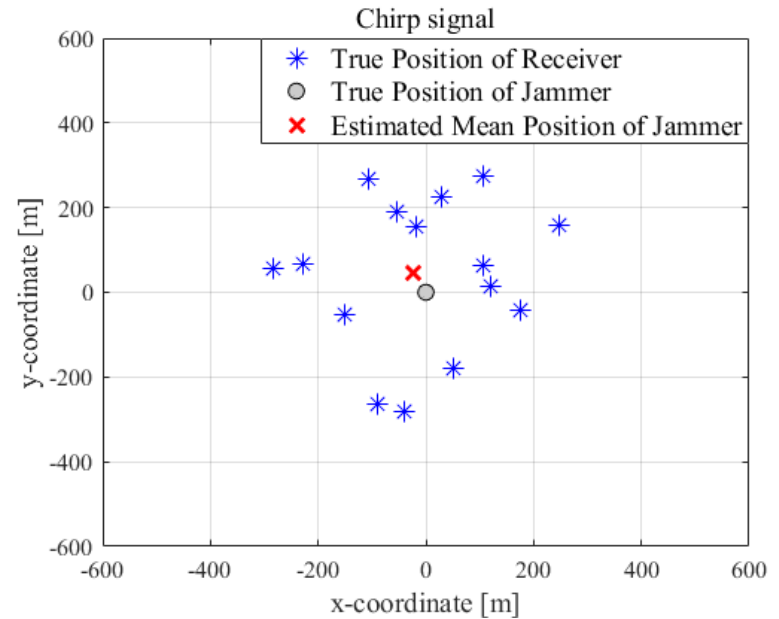


Fig 3 : the result of estimated position

	X coordinate	Y coordinate
Mean position error	-22.89 [m]	47.3 [m]

❖ Pulse jammer

- $$J_{pulse}(t) = \sqrt{2P_i} \text{rectpuls}(t, d, r) \cos(2\pi f_i t + \theta_i)$$

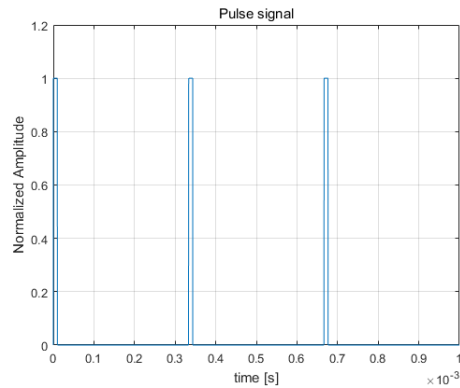


Fig 1 : Pulse signal over time

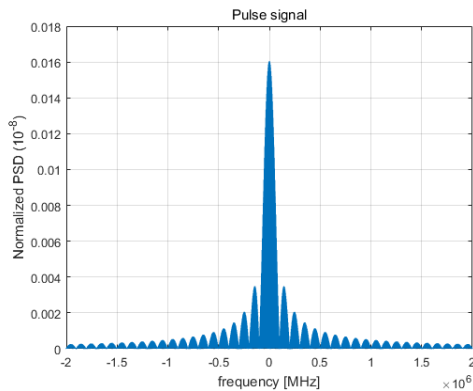


Fig 2 : FFT result of pulse signal

correlation →

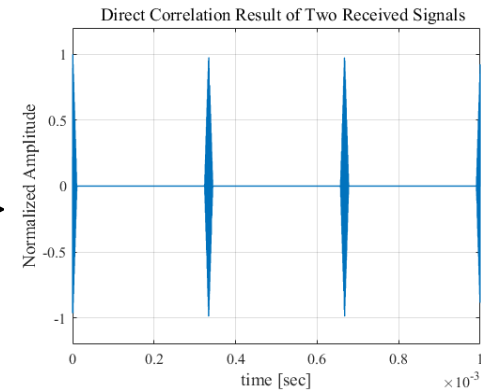


Fig 3 : signal correlation

Over time →

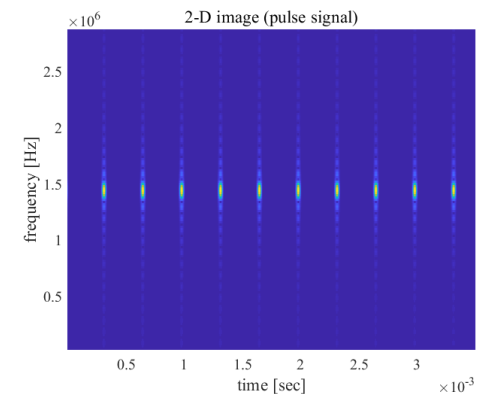


Fig 4 : 2-D image

❖ Pulse jammer

$$J_{pulse}(t) = \sqrt{2P_i} \text{rectpuls}(t, d, r) \cos(2\pi f_i t + \theta_i) + \text{noise}$$

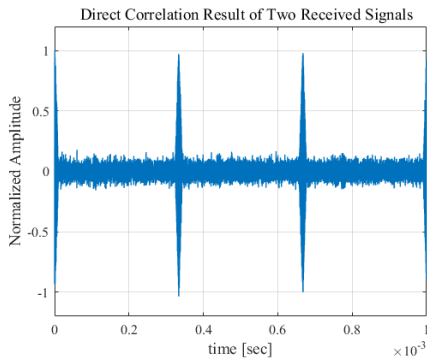


Fig 1 : 1ms correlation

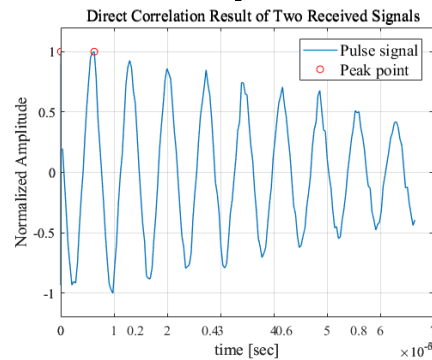


Fig 2 : 1µs correlation

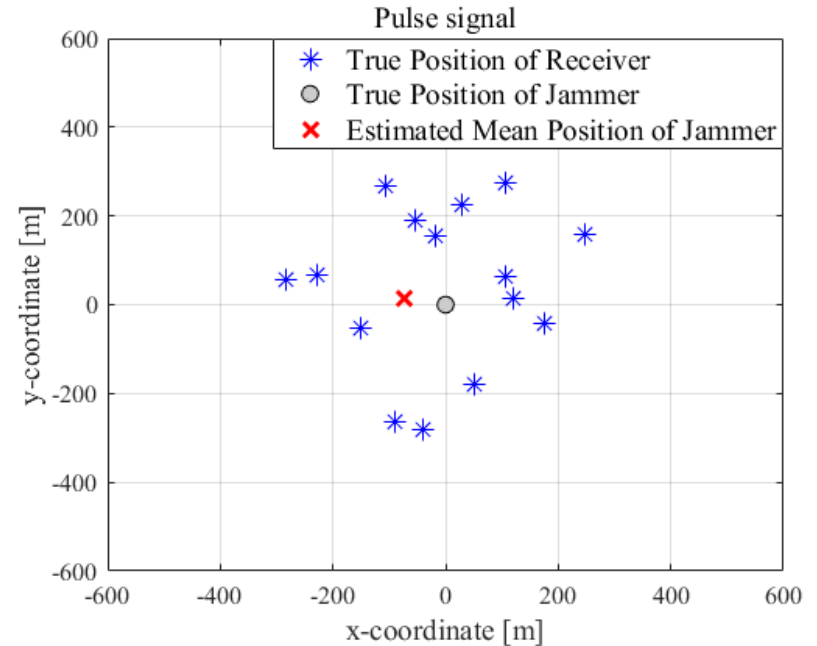


Fig 3 : the result of estimated position

	X coordinate	Y coordinate
Mean position error	-73.51 [m]	14.06 [m]

❖ Continuous Wave Interference(CWI)

- $J_{cwi}(t) = \sqrt{2P_i} \cos(2\pi f_i t + \theta_i)$

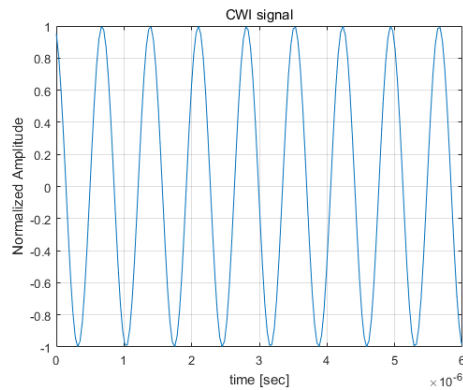


Fig 1 : CWI signal over time

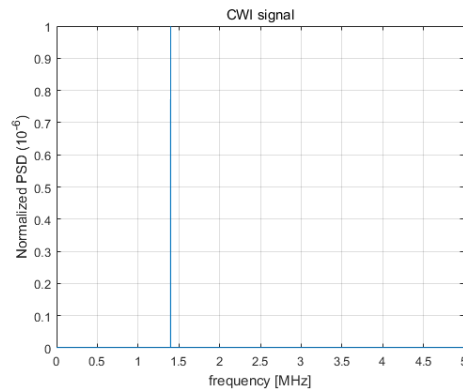


Fig 2 : FFT result of CWI signal

correlation →

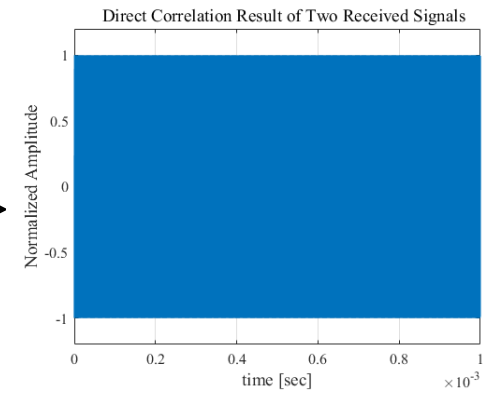


Fig 3 : signal correlation

Over time →

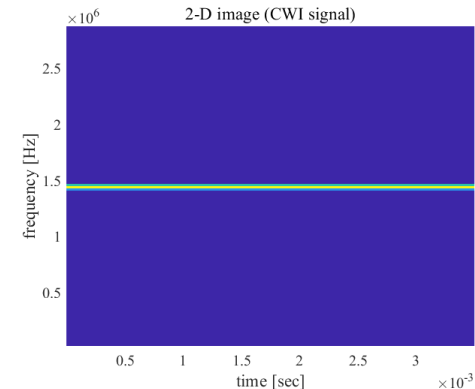


Fig 4 : 2-D image

❖ Continuous Wave Interference(CWI)

- $J_{cwi}(t) = \sqrt{2P_i} \cos(2\pi f_i t + \theta_i) + noise$

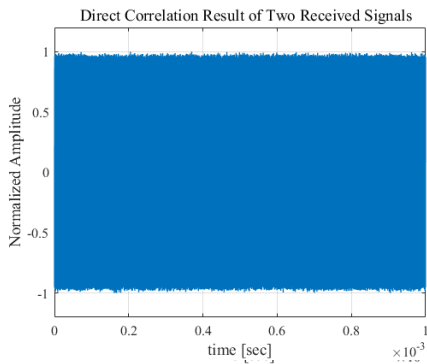


Fig 1 : 1ms correlation

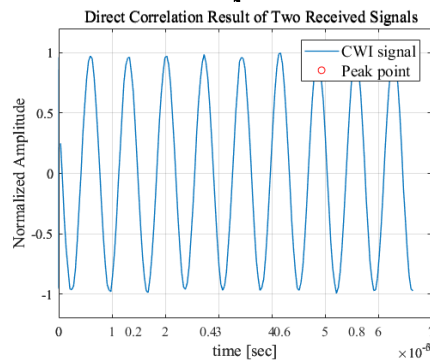


Fig 2 : 1μs correlation

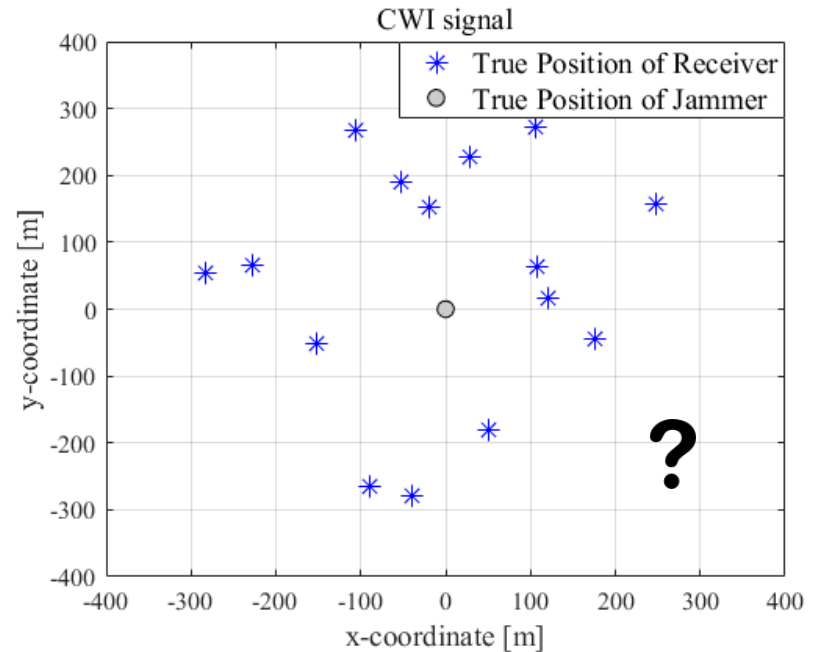


Fig 3 : the result of estimated position

	X coordinate	Y coordinate
Mean position error	???	???

❖ Simulation Result

Jammer type	Jamming detection	2D position error
MSI	O	45.64 [m]
BLWI	O	49.76 [m]
Chirp	O	52.55 [m]
Pulse	O	74.84 [m]
CWI	O	?

- The 5 type of jamming signal can be distinguished using 2-D image.
- Except for CWI signal, jammer position can be estimated using cloud server signals
- In same receiver arrangement, the MSI signal shows the smallest position error and the pulse signal shows the largest position error

Summary and Future Work

❖ Summary

- Propose the algorithm which can estimate the type and position of jammer using low-cost receivers
- In simulation with 5 difference jamming signal, we can determine the all type of jammer using 2-D image
- Except for CWI which has short repetition period, we can estimate the position of jammer.

❖ Future work

- formulate the correlation results of each jamming signal
- Analysis of Jamming position accuracy according to the power ratio between jamming Signal, noise and GNSS signal
- Analysis of Jamming position accuracy according to the arrangement of Low Cost Receivers
- base station of Korea's communication network can be Low-cost receiver

- [1] Samson, J. (2014), *An Introduction to Interference in GNSS-bands*, Presentation at ENC2014
- [2] Lindstrom, J., Akos, D. M., Isoz, O., and Junered, M. (2007), *GNSS Interference Detection and Localization using a Network of Low-cost Front-End Modules*, Proceedings of the 20th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS 2007), pp.1165-1172
- [3] Isoz, O., Balaei, A. T., and Akos, D. M. (2010), *Interference Detection and Localization in the GPS L1 Band*, Proceedings of the 2010 International Technical Meeting of The Institute of Navigation, pp.925-929
- [4] Scott, L. (2010), *J911: Fast Jammer Detection and Location Using Cell-Phone Crowd-Sourcings*, GPS World 21, no. 11.
- [5] Scott, L. (2011), *J911: The Case for Fast Jammer Detection and Location Using Crowdsourcing Approaches*, Proceedings of the 24th International Technical Meeting of The Satellite Division of the Institute of Navigation (ION GNSS 2011), pp.1931-1940
- [6] Strizic, L., Akos, D. M., and Lo, S. (2018), *Crowdsourcing GNSS Jammer Detection and Localization*, Proceedings of the 2018 International Technical Meeting of The Institute of Navigation, pp.626-641
- [7] Dosis, F. (2015), *GNSS Interference Threats and Countermeasures*, 1st ed. Artech House Inc.

Thank you for your attention !

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