GNSS cloud-data processing technique for jamming detection and localization

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ABSTRACT

In this paper, assuming that a jammer is located in an area where a large number of low-cost GNSS receivers are densely distributed and their received signals are gathered into a central processing unit like a cloud data, we propose a 2-dimensional time-frequency correlation method for the cloud data which can determine the type of jamming signal and estimate the jammer position. This method is applied for examining the similarity between arbitrary two signals acquired from different receivers, thereby discriminating the presence and the type of a jamming signal and also estimating the jammer position in the time-frequency domain. The availability of the proposed method is examined by a numerical simulation, where 14 GNSS receivers are randomly placed at the certain distances from the jammer, so that the J/S at the receiver is varying as distance increases. Finally, we analyze the results of the time-frequency correlation method to confirm that the jamming signal can be detected and the position of the jammer can be estimated.

1. JAMMING SCENARIO

1.1 Schematic depiction of jamming scenario

Fig. 1 is a schematic depiction of a scenario in which a jammer transmitting weak jamming signals is located between a number of low-cost GNSS receivers distributed in a dense density over a large area, and a processing procedure of the receiver data. The area where the jammer interferes with the receiver is set within a radius of 300 [m], so that in the jamming area, we assume the amplitude of the jamming signal is larger than the amplitude of the satellite signal. All receivers distributed over a large area continuously transmit the data of the received signal to the cloud server and the server monitors the jamming signal via the time-frequency correlation between the specific data. If the jamming signal is detected, the type of jamming signal, received jamming power, and TDOA information between the two signals are obtained by analyzing the result of the correlation method in the time-frequency domain. As a result, we estimate the position of the jammer by applying a position estimation method suitable for the type of specific jamming signal.

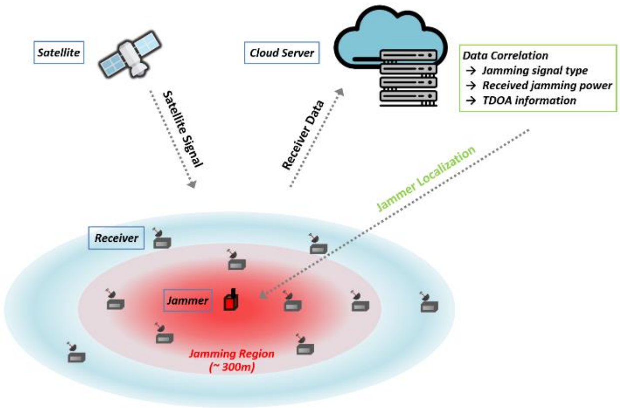

Figure 1 – Schematic depiction of jamming scenario and processing procedure of the receiver data

1.2 Types of jamming signals applied to the scenario

• Types of jamming signals

(1) Continuous Wave Interference (CWI)
- It is a sinusoidal wave, single-tone frequency signal within the GNSS frequency band.

(2) Matched Spectrum Interference (MSI)
- It uses the same spreading code as the GNSS signal and shows the same frequency characteristics.

(3) Band-Limited White Gaussian Noise Interference (BLWI)
- It has the white gaussian noise characteristic within the limited band, ideally the power spectral density is constant in frequency domain.

(4) Pulse Interference (Pulse)
- It has a large power in a very short time, and the form of pulse signal is generated according to the duty cycle, the pulse repetition frequency, and the pulse width.

(5) Chirp Interference (Chirp)
- As a continuous waveform signal with time-varying frequency modulation, it is technically easy to implement and has good jamming characteristics, so it is mainly used in In-car Jammer.

• **Modeling of jamming signals (Table)**

Type	Signal Modeling	Note
CWI	$\sqrt{2P_i}cos(2\pi f_i t + \theta_i)$	P_i : Jamming power f_i : Jamming signal frequency θ_i : Jamming signal phase $C(t)$: Spreading code $n(t)$: White gaussian noise $rect(t,d,r)$: Pulse with duration d, repetition frequency r at time t f_0 : initial frequency k : Chirp rate t_{chirp} : $0 \le t_{chirp} \le T_{sw}$ (T_{sw} : sweep time)
MSI	$\sqrt{2P_i}C(t)cos(2\pi f_i t + \theta_i)$	
BLWI	$\sqrt{2P_i}n(t)cos(2\pi f_i t + \theta_i)$	
Pulse	$\sqrt{2P_i}rect(t,d,r)cos(2\pi f_i t + \theta_i)$	
Chirp	$\sqrt{2P_i}cos\left[2\pi\left(f_0 + \frac{k}{2}t_{chirp}\right)t\right]$	

2. Jamming detection and localization using time-frequency correlation method

Correlation is generally applied between two data acquired from different receivers. Therefore, in Chapter 2, we explain the time-frequency correlation method using a jamming scenario for two receivers in another location as shown in Fig. 2

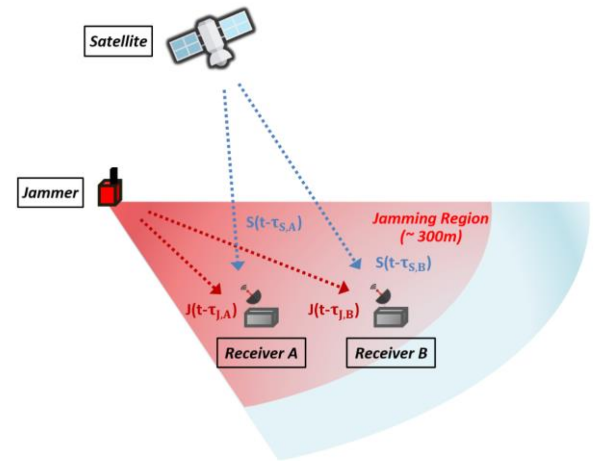

Figure 2 – Jamming scenario for two receivers in another location

2.1 Time-frequency correlation method

In order to detect jamming signals and estimate the jammer position, the time-frequency correlation method proposed in this paper consists of two correlations as follows

- Signal correlation in the time domain
- 2-D image correlation in the time-frequency domain

• **Signal correlation in the time domain**

This method means the correlation between the data of the two IF signals acquired from different receivers. Referring to Fig. 2, the equation representing this correlation, it is as follows

$$R(\tau) = r_A * r_B$$
$$= \{S(t-\tau_{S,A}) + J(t-\tau_{J,A}) + \eta_A\} * \{S(t-\tau_{S,B}) + J(t-\tau_{J,B}) + \eta_B\} \quad (1)$$

where r_A and r_B are received signal for receiver A and B, respectively, $\tau_{S,A}$ and $\tau_{J,A}$ are time delay of satellite and jamming signal for receiver A, respectively, $\tau_{S,B}$ and $\tau_{J,B}$ are time delay of satellite and jamming signal for receiver B, respectively, η_A and η_B are noise component for receiver A and B, respectively.

• **2-D image correlation in the time-frequency domain**

This correlation is to compare the 2-D images of the time-frequency domain generated with the IF signal data acquired at each receiver. Fig. 3 outlines a method of generating a 2-D image in the time-frequency domain for a single receiver. If the current time is 0, the preset signal length is n samples, and one signal sample corresponds to time T_s, the 2-D image can be obtained by connecting power spectrum density (PSD) expression of the IF signals over time. At this time, the frequency bin is expressed in other colors according to the magnitude of the power density.

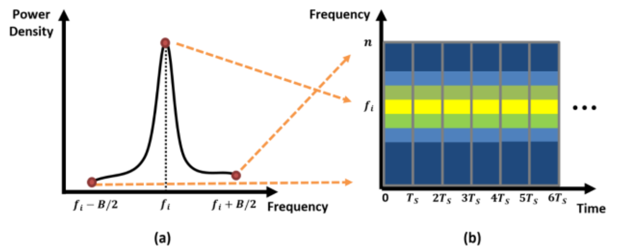

Figure 3 – Method of generating a 2-D image in the time-frequency domain for a single receiver. (a) PSD of n sample length IF signal at any one time (b) Generated 2-D image

2.2 Jamming detection using time-frequency correlation method

When the two IF signals in which the satellite signal and the jamming signal have different time delays are correlated in the time domain, the two correlation peaks exist at the index having $\tau_{S,B} - \tau_{S,A}$ and $\tau_{J,B} - \tau_{J,A}$ information. At this time, although the correlation form of the satellite signal is well known, the correlation form of the jamming signal shows different characteristics depending on the type. By analyzing this feature, it is possible to discriminate the presence and the type of jamming signal.

If the center frequency of the jamming signal differs from the satellite signal or continuously changes like the chirp signal, the frequency value with the largest power density will be different from the satellite signal center frequency in the time-frequency domain 2-D image. Frequency variation can also occur for fast-moving jammers, so the presence and type of jamming signal can be determined by monitoring them.

2.3 Jamming source localization using time-frequency correlation method

In the jamming scenario covered in this paper, the correlation peak value of the jamming signal is generally larger than that of the satellite signal for receivers existing in or near the jamming region. At this time, it is possible to obtain the TDOA information of the jamming signal between the receivers by analyzing the correlation peak. If we acquire this TDOA information from a large number of receivers, the position of the jammer can be estimated.

It is also possible to estimate the jammer position roughly by using the correlation of time-frequency domain 2-D images obtained from a lot of receivers. This exploits the fact that the 2-D image obtained from a receiver close to jammer has a higher power density than a far-away receiver. For example, if a large number of cloud-data obtained from region 'A' shows a 2-D image having a higher power density than that of region 'B', it can be seen that the jammer is located in the vicinity of region 'A'.

3. Simulation results analysis

3.1 Jamming scenario implementation

In the simulator, we assume that jammer can generate the aforementioned five jamming signals. In order to implement cloud-data, multiple receivers were arbitrarily placed at 50, 150, 250 [m] from the jammer. All receivers show C/N_0 of 44 [dB-Hz], regardless of distance. J/S of receiver depends only on the distance from jammer, so the J/S of the receiver is 30, 24, and 18 [dB] at 50, 150, and 250 [m], respectively.

3.2 Simulation result analysis of jamming detection

The following figures show the plot of the correlation result of two received signals for the five jamming signal types. We set the receivers are 50 and 250 [m] away from the jammer respectively.

Fig. 4 is the correlation result of the signals received from both receivers when the jamming signal is CWI. Since CWI is a continuous sinusoidal signal of constant frequency, the correlation result according to time comes out in the form of period. CWI only shows this property compared to other jamming signals. Therefore, we can recognize the detection and the type of the jamming signal by correlation in the time region.

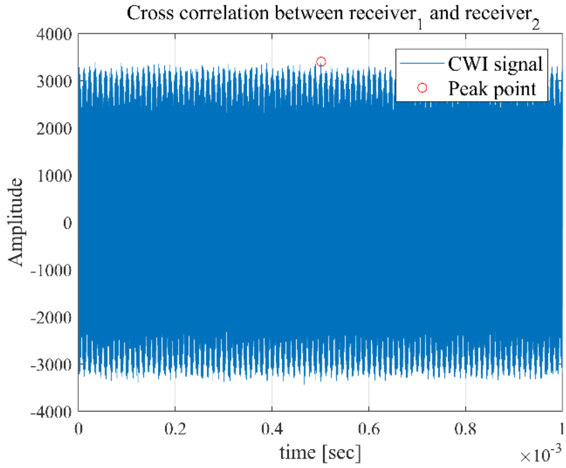

Figure 4 – Correlation result of two received signals for CWI

Fig. 5 is the correlation result of the signals received from both receivers when the jamming signal is MSI. MSI is a signal that uses the same spreading code as the existing GNSS signal. Therefore, it is difficult to detect jamming signal via the correlation in the time domain for MSI. However, assuming that the difference of doppler effect between two receivers is large for the satellite signals, the correlation result between the satellite signals may have small peak. Under these assumption, we can only obtain the correlation peak of MSI, and then detect it.

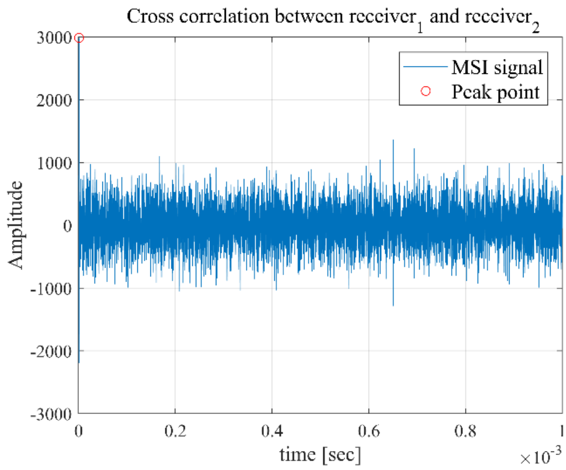

Figure 5 – Correlation result of two received signals for MSI

Fig. 6 is the correlation result of the signals received from both receivers when the jamming signal is BLWI. Since BLWI is white noise having a limited bandwidth, the correlation in the time domain has a sharp peak. Therefore, compared with the result of spreading code correlation of GNSS signal, it is possible to know the presence and the type of jamming signal.

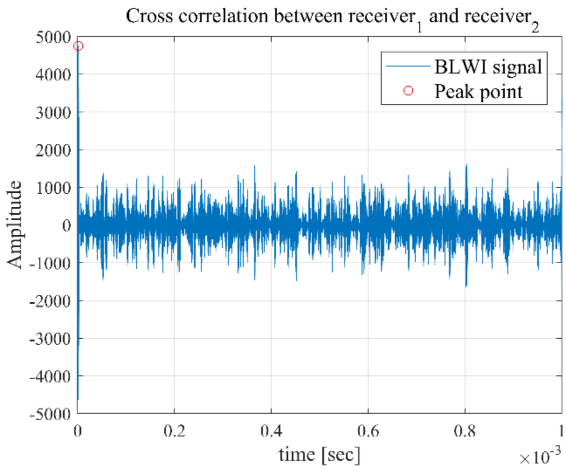

Figure 6 – Correlation result of two received signals for BLWI

Fig. 7 is the correlation result of the signals received from both receivers when the jamming signal is pulse. Since pulse radiates a signal of high power during a short period of time, the correlation value of the time region has a large peak at a constant period. By using this, it is possible to detect jamming signal and its type.

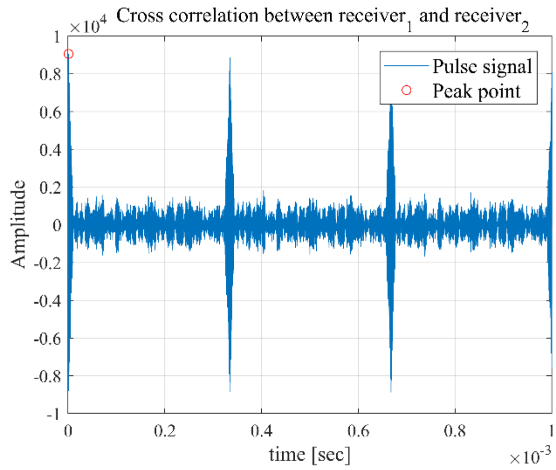

Figure 7 – Correlation result of two received signals for pulse

Fig. 8 is the correlation result of the signals received from both receivers when the jamming signal is chirp. Chirp signal is a continuous sinusoidal signal like CWI, but frequency varies with time. Therefore, the time of the signal used for correlation in analyzing the chirp signal is important. In Fig. 8, the time of the signal used for correlation is the same as the sweep cycle. Therefore, the correlation result is also displayed with one peak. However, if the time used for correlation is longer than the sweep period, the correlation result shows one main lobe with peak and side lobes with the same or smaller peak than main lobe. This is the same results as the pulse in which peaks of the same size are periodically displayed. Therefore, in order to distinguish these two signals, the time of the signal used for the correlation must be varied based on sweep cycle, so that the chirp signal has a side lobe with smaller peak than main peak. By using this, it is possible to detect jamming signal and its type.

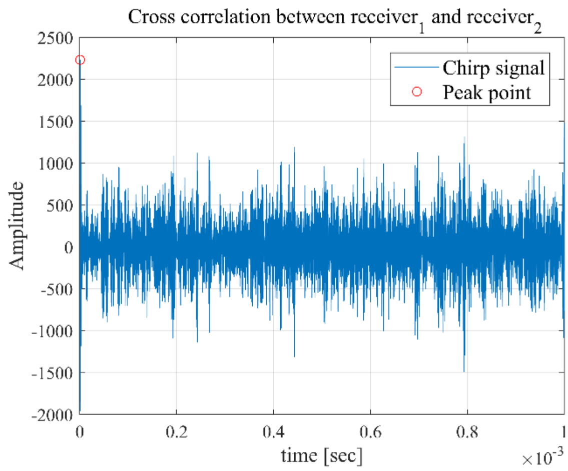

Figure 8 – Correlation result of two received signals for Chirp

In Fig. 4 ~ 8, only the correlation results in the time domain are presented, and the results of the time-frequency domain 2-D image correlation method will be added at a later.

The advantage of the proposed jamming detection method is that it is able to detect jamming signals and determine their type. This section proved this by simulation.

3.3 Simulation result analysis of jamming position estimation

In this section, we show the simulation results performed to prove that position estimation is possible via the proposed jamming detection algorithm. In this simulation, the position estimation result of the jamming signal source is shown in Fig. 9. The true jammer position was set to be located at the coordinates (0, 0), and the 14 receivers were randomly placed with 50, 150, 250 [m] distance from the jammer, respectively. Through correlation, TDOA between receivers was estimated. And through this results, the position was estimated by using the nonlinear least squares estimation (NLSE) method. As a result of the simulation, the result of estimated position of the jammer had about 28 [m] error from the true jammer location.

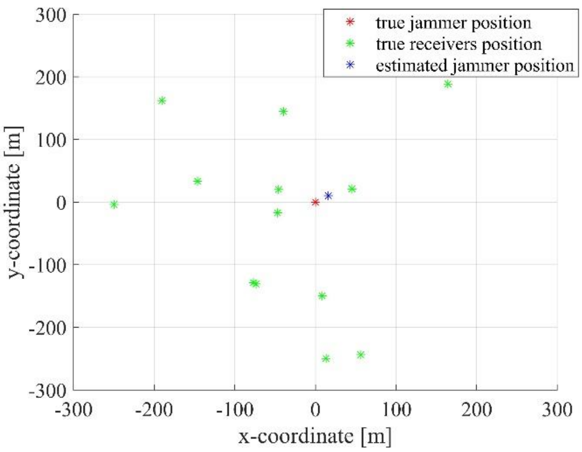

Figure 9 – The results of jammer position estimation by using proposed method

We proved that it is also possible to estimate the position of the jammer by using the proposed method. If we generate more receivers and the amount of cloud data increases, the accuracy of jammer position estimation will increase.

4. CONCLUSIONS

In this paper, assuming that jammer that transmits a weak jamming signal is located between a large number of low-cost GNSS receivers distributed at dense density in a wide area, we proposed a 2-dimensional time-frequency correlation method. It was assumed that data obtained from multiple receivers is processed through cloud-data computing, and the availability of the proposed method was examined by simulation.

By applying the time-frequency correlation method composed of two correlations, it is proved that different characteristics can be seen according to the type of jamming signals, whereby five jamming signals can be detected.

Through the jamming scenario where 14 receivers were arranged, it was proved that the jammer position estimation is possible by using the TDOA information of the jamming signals obtained as a result of the correlation between the data of receivers.

As a result, by using the time-frequency correlation method which was proposed in this paper, it is possible to discriminate the presence and the type of jamming signal and estimate the position of the jamming signal source, and if we could monitor a huge amount of the cloud-data simultaneously, it seems to be useful for the jamming signal monitoring.