Jamming Separation in GPS Signals Using Independent Component Analysis

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***Abstract* - The Global Positioning System (GPS) is a worldwide service use and is used as a reference for many other time base systems, altitude, latitude and longitude. Intentional jammers (jammers) have degraded the reception of GPS signals, causing the receivers to fall out of sync. The technique employed in Independent Components Analysis (ICA) provides the ability to separate and mitigate the interference (jamming). A Software-Defined Radio (SDR) was used to confirm the effectiveness of this technique against jamming.**

Keywords - GPS; jammers; ICA; jamming; SDR.

I. INTRODUCTION

The Global Positioning System (GPS) is one of the most used telecommunications systems, used in various applications like online mapping, car tracking, traffic control, etc. [1]. To avoid the localization of a target by GPS, some portable devices were developed to interfere with localization signal reception.

The received GPS signal normally has a low power, i.e., -160 dBm, with approximately 20 MHz of bandwidth. Thus, a jammer device, that produces the interference signal in the same frequency bands with the GPS signal, can interrupt the signal reception for kilometers [2]. The utilization of these devices are forbidden, but they can be easily acquired in the market [3].

Some techniques have been developed to combat the jammers as adaptive filtering [4][5], filtering in the time - frequency domain [6][7], adaptive antennas [8][9], among others. In this paper, we propose the utilization a blind source separation technique Independent Component Analysis (ICA) to separate the GPS signal from the interference. ICA has an efficient implementation and good performance in the low Signal-to-Noise Ratio (SNR) situations, as is the case of GPS signals.

We used real measurement signal to validate the proposed utilization and the obtained results shows the efficiency of ICA in the GPS signal recovery.

This article is arranged as follows: Section II presents the software-defined radio, in Section III is a brief description of the method of analysis in independent components (ICA). Section IV presents the used software-defined radio. The application of the method proposed in the situation is defined in Section V. Finally, the results and conclusions are in Section VI.

II. SOFTWARE-DEFINED RADIO

The Software-Defined Radio (SDR) is designed as a reconfigurable and flexible arrangement of radio that is based on a software [16]. Thus, it provides the possibility of implementing several radio configurations, only by changing software parameters, taking advantage of the same hardware structure. Moreover, thanks to the high processing power of the platform, one can use a more elaborate signal processing with real-time radio systems in a fast development environment of use applications.

GNU Radio is a free software platform and open source used in the development of hardware without radios in a simulation environment, or with an external RF hardware cost. There are pre-defined blocks in an internal library or created by the user, which operate independently and, when connected, form software-defined radios.

The Universal Software Radio Peripheral (USRP) [17] is an RF device consisting of a motherboard and a set of plates daughters. On-board analog-to-digital converters are in the reception area (path from the antenna to the processing system), digital to analog converters in the transmission zone (path processing system to the antenna) and an FPGA to multiplex data the daughter card from reception to the computer and vice versa.

Each daughter card is designed for a range of frequencies and, in a typical configuration, are arranged into four units: two for transmission and two for reception.

III. INDEPENDENT COMPONENT ANALYSIS

The Independent Component Analysis (ICA) [10] is a blind source separation method, where the base on the linear mixture of signal sources, the objective is to recover a statistically independent and non Gaussian representation of each source.

Consider n statistically independent sources $(s_1, s_2, s_3, \dots, s_n)$ and m measurements of mixture of these sources, $(x_1, x_2, x_3, \dots, x_n)$, written as a linear combination of the sources by

$$x = As. \tag{1}$$

where $$x = (x_1, x_2, x_3, \dots, x_n)^T. \tag{2}$$

is the measurement vector, known a priori. The mixing matrix A and the source vectors,

$$s = (s_1, s_2, s_3, \dots, s_n)^T. \quad (3)$$

are unknown.

If matrix A is known, to recover the source vector s

$$s = A^{-1}x. \quad (4)$$

however as matrix A is not known, it is necessary to estimate a separation matrix W that recover the source vector s, using only the measurement vector x:

$$\hat{s} = Wx = WAs. \quad (5)$$

Figure 1 represents the block diagram of ICA.

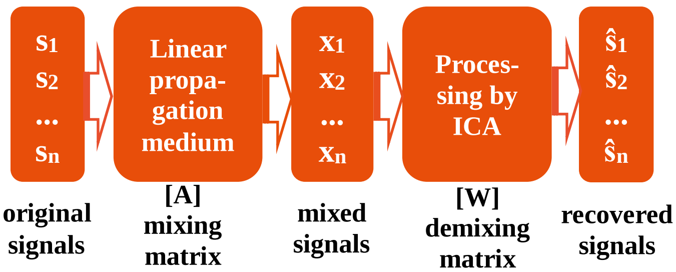

Figure 1. Block diagram of the ICA.

The first step for the application of ICA is to choose a cost function. After, an optimization method to optimize the cost functions must be chosen. In this work, we use an efficient method to perform these tasks, the FastICA [18], which is based on maximizing nengetropia [10], using as cost function the nonlinear function:

$$g = y^3. \quad (6)$$

and symmetrical orthogonalization.

IV. Software-Defined Radio Used

For the verification of the application of ICA result to separate the GPS signal jamming, a software-defined radio was used, GNSS-SDR, proposed in [19]. This radio implements an algorithm for the acquisition and demodulation of the signal and another location algorithm, based on information derived from the first.

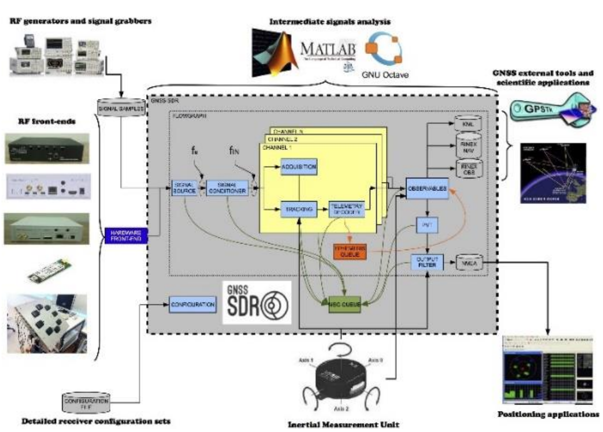

Figure 1 - Overview Software-Defined Radio GNSS-SDR [19].

V. Application of the Method in Proposed Case

To demonstrate the application of the proposed method used a GPS signal from the Crawdad database [11], represented in Figure 3. This signal has central frequency of 1575.42 MHz, sampling rate of 6.4 GHz, span of 5 MHz and 320000 samples were registered. It was acquired using a Tektronix RSA3408A real time spectrum analyzer, a Rojone A-GPSA95NS antenna, Rojone AMA-061B amplifier and a DC blocker.

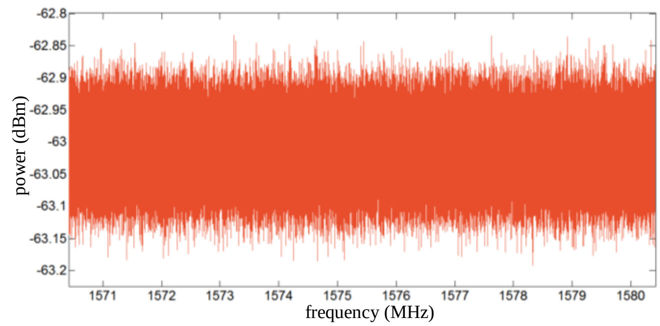

Figure 3. GPS signal spectrum.

As interference signal was used a chirp signal signal, generate using Matlab®, shown in Figure 4. This signal has a central frequency of 1575.42 MHz (GPS L1 Band), initial frequency (f_0) in 1570.42 MHz, final frequency (f_1) in 1580.42 MHz and a quasi static sweeping mode, whose instantaneous frequency is given by

$$f_i(t) = f_0 + (f_1 - f_0)t^2. \quad (7)$$

according to signals emitted by GPS jammers [12][13].

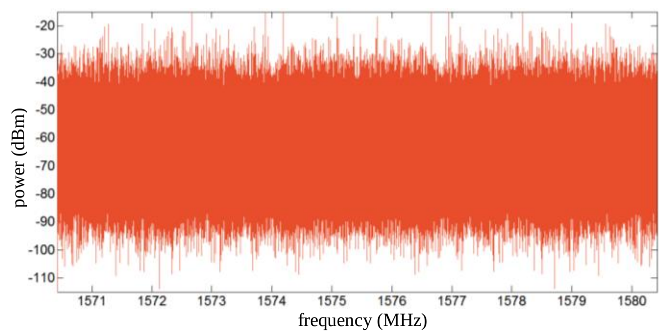

Figure 4. Spectrum chirp signal (interference signal).

FastICA [18] was the algorithm used to separate the mixture of the GPS and Chirp signal. According to [14] and [15], ICA has some restrictions, and one of them is the signal sources have non Gaussian distribution. When the sources are Gaussian there is no guarantee of source recovery. GPS signal has probability distribution near of Gaussian (2.971 kurtosis).

However, when we apply the FastICA to some mixture of GPS signals, the sources were recovered. As ICA does not guarantee prefect recovery of phase, or order of the recovered signal, as shown in [14] and [15], we used the cross

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correlation to test the signal correspondence between original and recovered signals.

When compared by correlation, the original GPS signal and the first recovered component, shown in Figure 5, the obtained correlation -0.0067.

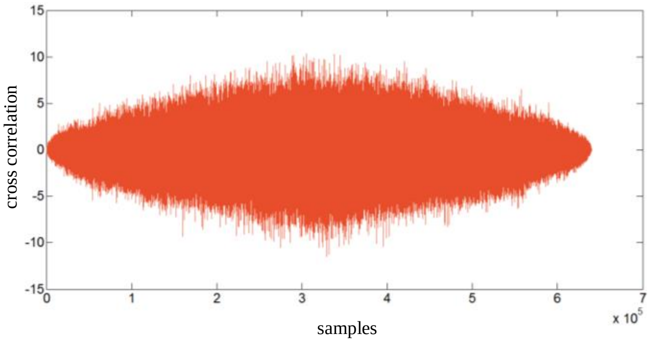

Figure 5. Cross correlation between the original signal and the GPS signal chirp recovered.

Figure 6 shows the cross correlation between the original chirp signal and second recovered component, that gives a correlation coefficient of -0.0049.

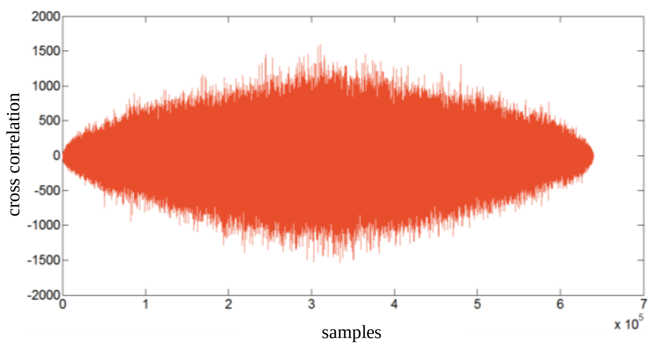

Figure 6. Cross correlation between the original chirp signal and the recovered GPS signal.

The results shown in Figures 5 and 6 indicate the similarity between recovered signals. In the comparison between the original GPS signal and the second recovered component, presented in Figure 7, the correlation coefficient is 0.9987.

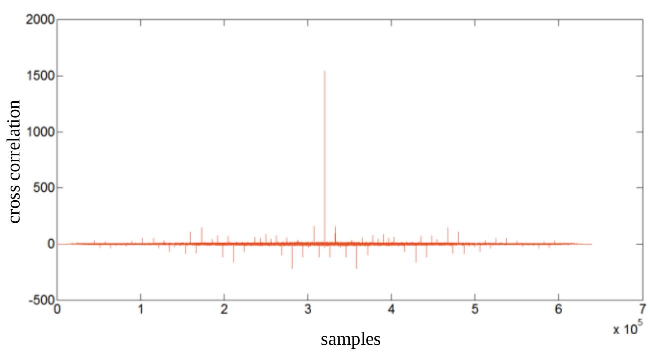

Figure 7. Cross correlation between the original and the recovered GPS signals.

In Figure 8, the comparison of original chirp signal and the first recovered component, the correlation coefficient is -0.9998. In these last comparisons, it was observed that signal has great similarity.

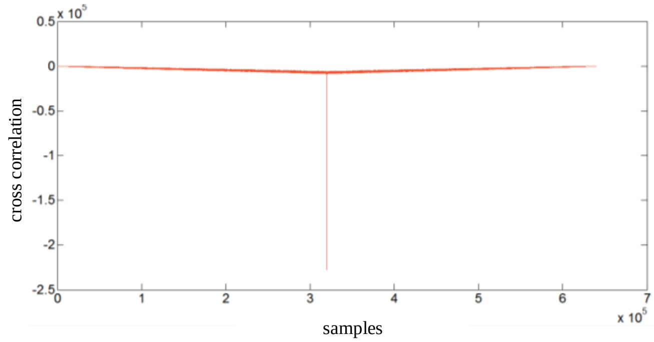

Figure 8. Cross correlation between the original and recovered chirp signals.

As GPS signals has its data modulated by C/A code (a PRN-Code broadcast at 1.023MHz which spreading the data over a 2MHz bandwidth), which in turn modulates the L1 carrier (1575,42 MHz) using Binary-Phase-Shift-Keying (BPSK), the original GPS signal (Figure 9), the mixture of the GPS signal and signal interference (Figure 10) and the recovered GPS signal (Figure 11) were demodulated.

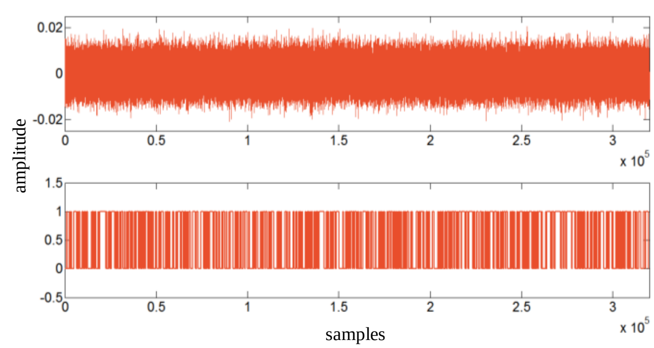

Figure 9. Original GPS signal demodulated.

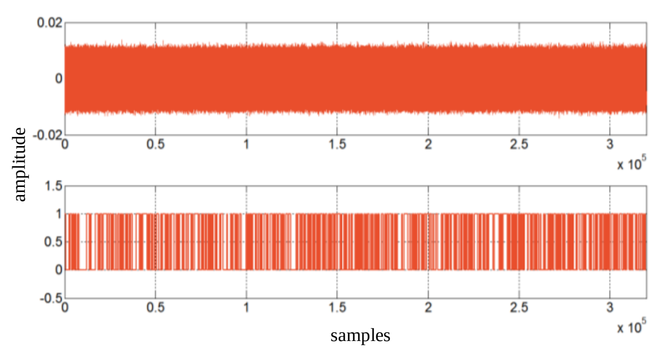

Figure 10. GPS signal mixed to interference and demodulated.

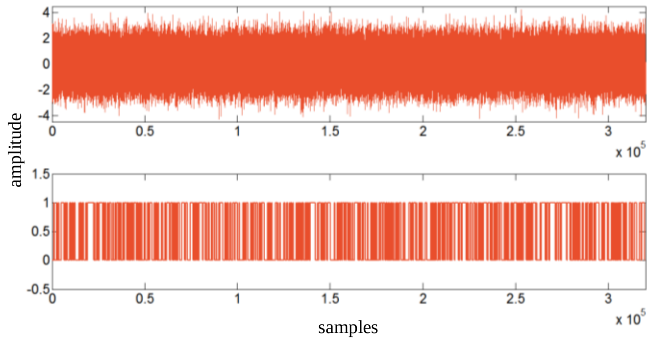

Figure 11. GPS signal demodulated recovered.

After that the correlation coefficient were obtained and the results are original and mixed signal (0.0501), mixed and recovered (0.0434) and original and recovered signals (0.9935).

VI. RESULTS AND CONCLUSION

Since FastICA does not guarantee that the original signals are recovered in the same order, we made four comparisons between the original signals and the signals recovered to detect which pairs of signals corresponded. In this test, it was found that the original GPS signal had a low correlation (-0.0067) with the first independent component and a high correlation (0.9987) to the second one. This indicates that the second independent component of the GPS signal is recovered with the same phase.

Then, it was discovered that the original chirp signal had high correlation with the first independent component (-0.9998) and low correlation with the second (-0.0049). This indicates that the first independent component represents the chirp signal recovered with reversed phase.

To confirm the first conclusion, a second test was done. The test compared three GPS signals between them: the original, the original mixed with interference and the recovered. The correlation between the original and blended signals, and between the mixed with the recovered was low (0.0501 and 0.0434, respectively). This indicates that the compared signals have no similarity. In the confrontation between the original and recovered signals, a high coefficient of correlation was achieved (0.9935), indicating that the signals tested have great similarity.

In this case, it is concluded that the chirp signal actually represented an interference to the GPS signal, as the signal was demodulated when mixed, did not correlate with either the original signal as the recovered signal. Another conclusion, and the most important, is that the analysis in independent component (ICA) was really a tool capable of separating interference (chirp signal) of the desired signal (GPS), since the comparison between the original and GPS signals recovered by ICA, could become a very high similarity.

Finally, as obtained by the RDS-GNSS position coordinates corresponding to the original GPS signals, mixed and recovered, has the following output: the difference between the original coordinates of the extracted GPS signal, and the retrieved signal was only 68 meters, as shown in Figure 12. While the GPS signal mixed with the chirp interference will not return any coordinate point indicating that there was actually a loss of synchronization with the GPS satellites, if the jamming still present.

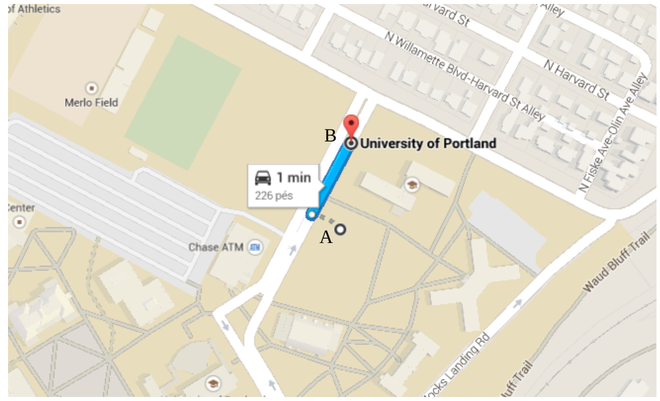

Figure 12. Difference between the original GPS point (A) and recovered point (B).

This work was the result of the first research on the topic in question. In the future, it will continue to be developed, so that consideration be other mitigating interference in GPS signals, such as the multi-jamming and other waveforms.

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