A New Method For Mitigation Of Cross Correlation In GPS Receiver

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***Abstract*—An algorithm for GPS receiver performing to mitigate cross correlations between weak satellite signal and strong satellite signals is presented. By using the tracking result of strong signal, the cross-correlation and cross correlation sequence between weak signals and strong signal can be computed, further modifying the local generate C/A code to drive the cross correlation to zero. The advantage of this method is that it does not require estimation of the strong signal amplitude and it partially independent of the data bit value. Simulation result shows it can eliminate the interference of 75%, and this method is at the cost of sensitivity loss of 0.28dB.**

Keywords- cross correlation; relative doppler frequency shift; code phase difference

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1 Introduction

Most of the navigation receivers recently is working in urban area or other place where the signal is shadowed by mountain or the tree, this will bring a problem that the receiver can not receive sufficient normal signals from satellites, some received signals are reflected by buildings or mountains, or shadowed by trees, and if these signals are so weak that it might be shaded by the normal signals.

Cross correlation is a multi-address interference in spread spectrum communications such as GPS navigation system. As we know, the cross correlation between PRN codes from different satellite is not zero, the peak value of self-correlation is higher than peak value of cross correlation of 24dB. If a signal is shadowed or reflected, this signal will be greatly attenuated, and its power intensity is far lower than normal signal's. Therefore the strong signal may interfere the processing of weak signal, which is called near-far problem. In this case of near-far interference, GPS receiver can't receive and process the weak signal if it is at a very low power. With aim to enhance receiver's sensitivity, many schemes such as successive interference cancellation in [1][2][3] and parallel interference cancellation in [4] are presented. Cancellation techniques resolve the problem by constructing the strong signal and subtracting it from the input signal data-stream before baseband down-conversion and de-spreading. The main advantage of cancellation method is that they are relatively simple. Subspace projection techniques represent an alternative approach to resolving the cross-correlation problem in [5][6]. With these techniques, rather than using a de-spreading code that is matched to the transmitted code of the weak signal, a different code that rejects the strong signal cross correlations while still being able to observe the desired weak signal is used instead, with the new de-spreading code having the property of being able to extract the component of the weak signal subspace that does not lie within the interference subspace. The reason for the method not being widely used is due to the difficulty in constructing the required codes in real time, with the code construction technique requiring a significant amount of matrix arithmetic on vectors and matrices that have a length defined by the number of samples in each C/A code epoch.

Usually the cross-correlation between PN codes is negligible. For GPS signal, the cross correlation between PN codes is about 24dB less than the peak value of self-correlation, even under the condition of Doppler effect, cross correlation is lower than self-correlation is about 20dB. This is enough to determine the self-correlation peak value, but if the strong signal is higher than the weak signal of more than 20 dB, it would be hard to distinguish the self-correlation result of weak signal from cross-correlation between strong and weak signal, then it can cause wrong acquisition and can not tracking the weak signal.

2 Principle of cross-correlation mitigation

Provide the composed signal comprised by a strong signal (S1), which modulated by PN1, and a

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weak signal (W1), modulated by PN2, the composed signal can be described by $S_1 \times PN1 + W_2 \times PN2$, let the received signal correlate with local duplicated PN2 code PN2R, the correlation result is

$$R = \sum \{PN2R \times (S_1 \times PN1 + W_2 \times PN2)\} \quad (1)$$

where $\sum$ means the sum of cross correlation and self correlation result, since the standardize correlation between PN2 and PN2R is 1, so it can be described as:

$$\sum \{S_1 \times PN1 \times PN2 + W_2\} \quad (2)$$

In order to get the self correlation result of W2, the $S_1 \times PN1 \times PN2$ must be removed from the $\sum$. Traditional method is to predict the cross correlation value and subtract it from the R. In this paper, we generate a modified PRN code PN2R'to Provide the sequence, the cross correlation $S_1 \times PN1 \times PN2$ is driven to 0, that is to say, the cross correlation is driven to negligible level, while still being able to observe the required weak signal.

So this method, the main problem is how to modify the local C/A code Cw that eliminates the cross correlations. Given two binary pseudo-random sequences (PRN) cw(i) and cs(i) both of length N, define two parameters:

$$cc_{ws}(i) = c_w(i) \cdot c_s(i)$$

$$CC_{ws}(j) = \sum_{i=1}^{j} cc_{ws}(i)$$

where $cc_{ws}(i)$ is the cross correlation sequence, $CC_{ws}(j)$ denote the partial cross correlation between weak signal PRN code and strong signal PRN code. The value i is from 1 to N, and $j \in [1, N]$. A w subscript refers to a weak signal PRN and an s subscript refers to strong signal. A weak signal is any signal that has a power level less than the cross correlation threshold of 24 dB below the strong signal.

Clearly, a non-zero cross correlation $CC_{w\varepsilon}$ occurs because the cross correlation sequence cc_{ws} is unbalanced, which means the number of 1's is different to the number of -1 's. Thus a method by which modifying the weak PRN c_w to balance the the cross correlations cc_{ws} is suggeated.

3 Cross-correlation mitigation

3.1 Single jammer signal

For cases of single strong jammer signal, the main problem is how to deals with a single strong GPS signal that interferes with the acquisition and tracking of weaker signals. It is assumed that the strong signal is being tracked and as such, the code sequence for the strong signal $c_{s1}(i)$ is available. Since cross correlations are a form of structured interference, the noise is inherently predictable for a given location, with the prediction of the noise being easier in the case of zero Doppler. Furthermore, since the changes in code phase due to Doppler frequency are relatively slow (even if the Doppler frequency was not zero), the change in the cross correlation sequences are also relatively slow and do not change significantly between code epochs.

The C/A code of GPS system is Gold code, according to character of Gold code, no changes will be necessary 75% of the time since significant cross correlations only occur with a probability of 25%. During this 25%, only a small number of chips need to be changed to significantly reduce the cross correlation level, albeit at the cost of a small reduction in sensitivity since c_w' is no longer matched to c_w. These changes are independent of the value of any navigation message data-bits since the effect of the data-bit value is simply to change the sign of the resulting cross correlation, which is driven to zero anyway. However, problems will be face when a data-bit change occurs since this can be considered as an un-modeled change in the strong code.

One simple method to generate the required code is to make immediate changes to the starting code until the cross correlation has been reduced to the required level. To do this, the cross correlation for the next epoch is pre-calculated thereby determining the amount of change required to eliminate the cross correlation. This is followed by the modification process, which for a single C/A code jammer requires approximately 32 chips in a sequence of 1023 chips be modified since the cross correlation level is either -65 or 63. Chips that need to be changed can be determined through examination of the cross correlation sequence $cc_{ws}(i)$, with the aim of ensuring that the sum of the sequence after a full epoch is driven to zero. In the case where the cross correlation is positive (63), the cross correlation sequence has more ones than minus ones and it is necessary to invert the sign of approximately 32 ones. This can be achieved by inverting the sign of 32 chips in c_w, where the indices of the chips to be inverted are determined by the indices at which $cc_{ws}(i)$ have values of 1. A similar set of changes is made for a negative cross correlation except that this time it is necessary to create more ones in $cc_{ws}(i)$. This gives rise to the following flowchart of the algorithm:

In Fig.1 the sample weighting factor W usually set to 2 when the sample number is 1 per chip, if it is not 1, W will be adjust to $2 \times snc$, snc is the sample number per chip.

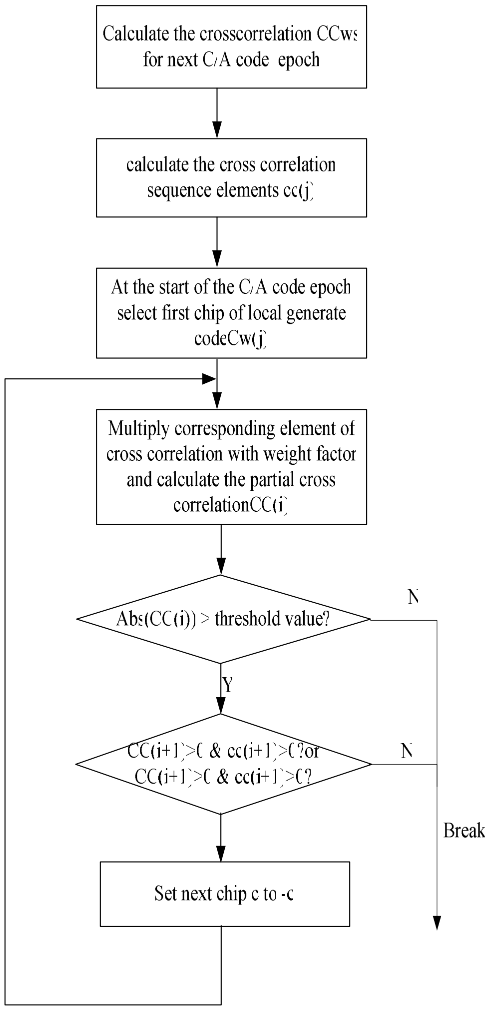


Fig. 1 Flowchart of the algorithm

3.2 Multiple jammer signal

When there are multiple strong signals, the single jammer algorithm will be invalid because the algorithm only allows for a single jamming PRN code. Although it would be possible to use this algorithm where the single strong code is replaced with a linear combination of strong codes, this introduces a dependence on the value of the data-bits thereby negating one of the advantages of the method and therefore is less preferred.

The multiple jammer problem can be stated as the problem of constructing a code sequence $\hat{c}_w$ such that for each strong signal code c_{s1}, c_{s2} and c_{s3} the associated cross correlations $CC_{\hat{C}wcs1}$,$CC_{\hat{C}wcs2}$ and $CC_{\hat{C}wcs3}$ are reduced to acceptable levels. The single jammer algorithm cannot be individually applied to each of the codes in turn because a partial set of changes to c_w to reduce the cross correlation with c_{s1} may be undone or negated when further changes are made to reduce the cross correlation with cs2 or previously small cross correlations may be exacerbated. As a result, a valid solution will ensure that one set of changes do not interfere with another set of changes

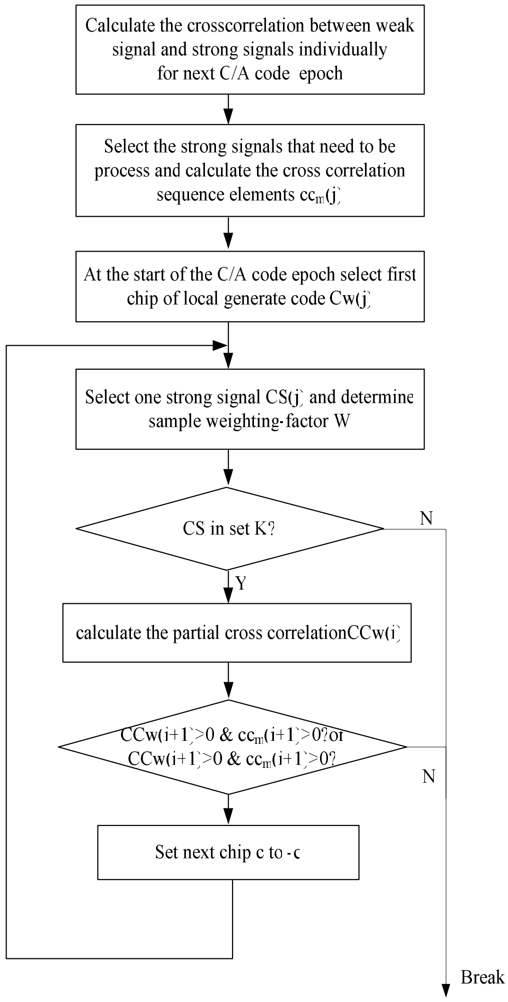


Fig. 2 Flowchart of multiple jammer mitigation scheme

To show how to achieve this objective, consider the partial cross correlations for each strong signal $CC_{ws1}(j)$, $CC_{ws2}(j)$ and $CC_{ws3}(j)$, where the changes made to c_w have the effect of driving $CC_{\hat{C}wcs1}$,$CC_{\hat{C}wcs2}$ and $CC_{\hat{C}wcs3}$ to small values. In the one-jammer case, the changes are such that when CCws1 is positive/negative, some locations at which $CC_{ws1}(j)$ is rising/falling are changed so that $CC_{\hat{C}wcs1}(j)$ is falling/rising instead. These changes ensure that by the time reaches N, the partial cross correlation terminates near zero as required. The same concept can also be applied in the case of multiple strong signals, except that the locations at which changes can be made to c_w are constrained by the codes of the other strong signals. Suppose that modifications to c_w are being made to reduce/increase the cross correlation CC_{ws1} with c_{s1}, then provided changes to c_w are constrained to those indices that cause $CC_{\hat{C}wcs2}$ and $CC_{\hat{C}wcs3}$ to remain unchanged, then the changes will have been beneficial. These constraints on $CC_{\hat{C}wcs2}$ and $CC_{\hat{C}wcs3}$ being unchanged can be achieved by only making changes at pairs of indices m and n such that $cc_{\hat{c}ws2}(m)+cc_{\hat{c}ws2}(n)$ and $cc_{\hat{c}ws3}(m)+cc_{\hat{c}ws3}(n)$ are 0, but $cc_{\hat{c}ws1}(m)+cc_{\hat{c}ws1}(n)$ is positive/negative as required. In this particular case, inverting the sign of $cc_{\hat{c}wsk}(m)$ and $cc_{\hat{c}wsk}(n)$ by inverting $\hat{c}_w(m)$ and $\hat{c}_w(n)$ for K values of 1, 2 and 3 leaves the cross correlations with 2 and 3 unchanged but improves the cross correlations with 1. The process can then be repeated on each of the strong signals that have a large cross correlation with the weak signal code until all cross correlations are reduced. This algorithm can be restated as follow flowchart:

4 Doppler effect

The method suggested above are capable of reducing cross correlations when the Doppler difference between the strong and weak signals is small, when there is a non-zero Doppler difference, problems quickly become apparent. The reasons for these failures are that I & Q cross correlations are different due to different relative Doppler frequency shift terms on each of these channels.

Relative Doppler frequency shift presents a number of different problems for cross correlation mitigation. Firstly, it is clear that these mixing terms can be thought of as applying different weighting to different segments of the strong PRN code, which means that the rotating jamming PRN code is completely different to the fixed PRN code. In particular, the fixed PRN codes are two bit sequences whereas the mixed PRN codes are analogue signals that are effectively multi-bit. This represents a problem for the algorithm presented here that relies on being able to identify locations within the cross correlation sequences that meet certain constraints, under the assumption that the cross correlations are a function of those cross correlation sequences.

Since the relative Doppler carrier (RDC) phase varies between C/A code epochs, the strong jamming PRN code is no longer periodic with a single C/A code period since it is modulated by the RDC term. This makes prediction of the next C/A code value difficult since it is necessary to take into account the exact frequency and phase of the RDC mixing terms. Knowledge of the exact frequency and phase of the RDC mixing terms requires that the exact frequency and phase of the strong signal must be obtained, as well as knowing the offset from these values for the mixing being applied to search for the weak signal. The former can be obtained from the strong signal digital controlled oscillator (DCO) phase values, assuming that the DCO is phase locked to the strong signal. The latter can be obtained by differencing the weak DCO phases from the strong DCO phase, with an adjustment included to account for the difference between the I & Q channels. It should also be pointed out that the RDC modulation of the strong PRN code is equivalent to modulation of the strong PRN by the product of a square wave given by the sign of the RDC and a non-negative weighting factor given by the magnitude of the RDC. This serves to reinforce the fact that the RDC completely changes the strong code since even a change of a few elements in phase will result in a completely different strong code.

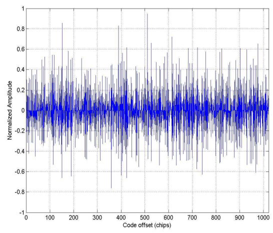
Another difficulty caused by relative Doppler carrier is that the significance of segments of the PRN code change depending on the phase of the RDC. An extreme case occurs for zero RDC where all of the cross correlation will be in I channel and none will be in the Q channel. This means that care needs to be taken during the mitigation process to ensure that changes are not made at locations where the weighting of the jamming is low and there is no significant effect on the total amount of cross correlation.

Given these problems, it is strongly preferred that relative Doppler frequency shift effects be taken into account when performing the mitigation. The first requirement is the need for separate mitigation for both I and Q channels. This means that it is necessary to duplicate the process on each channel, with only the RDC inputs to each of those channels being different thereby resulting in different outputs. Since the final detection process involves taking the magnitude of I and Q correlations, this ensures that the cross correlations in both I and Q channels will be controlled.

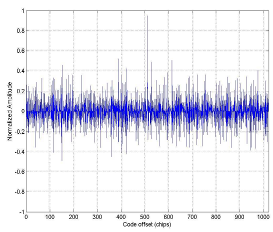
The second question is how RDC effects can be incorporated into the solution while still permitting the methods applicable to the non-rotating sequences to be employed. The answer is to construct a more realistic version of the strong code sequence as the product of the sign of the RDC and the original code sequence. Use of this new sequence rather than the original sequence means that except for a non-negative weighting factor given by the magnitude of the RDC sequence, the constraints and the process of locating these constraints are exactly as previously given. However, care still needs to be taken to ensure that when changes are made, the weighting of those changes is properly accounted for.

5 Simulation result and analysis

With aim to confirm that the proposed method is effective in improving the sensitivity of weak signals in the presence of strong signals. The simulation consists of two steps. The first step consists of the generation of a single epoch (one millisecond) of intermediate frequency (IF) data for all of the specified satellites with specified amplitude, Doppler frequency, carrier phase and code phase. Since only a single epoch of data was generated, these simulations do not consider the effect of data-bit transitions. A single epoch of data is also not sufficient to detect very weak signals in the presence of typical noise, so none of the generated signals include additive white noise, so any noise-like effects in the outputs are due to limitations of the technique. The second step of the simulation is to attempt detection of the weak signals assuming that the strong signals are being properly tracked in a phase-locked loop (PLL) and delay locked loop (DLL). The known truth data from the input simulations were used as a substitute for strong signal PLL and DLL outputs. Detection of the weak signal is specified for a single frequency bin with all code phases being examined at a code-spacing consistent with the IF sample period. Since a real



(a)



(b)

Fig. 3 Time domain glide correlation results (single jammer)

search for a weak signal does not have knowledge of the true weak signal carrier frequency and phase terms, errors for these terms may be specified in the simulation. The output for all code phases for I, Q and magnitude terms are then be displayed.

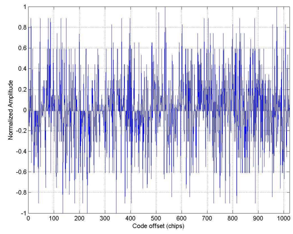
The parameters used in simulation are given below:

IF frequency: 4.096 MHz; Sample/chip: 8;

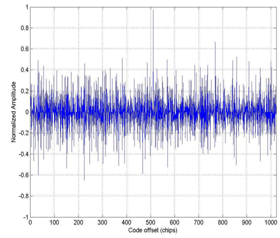
Relative Doppler limit: 0.125;

Jammer /weak signal: 15dB

Fig. 3 is the simulation results under the condition of single jammer, and Fig. 4 is the simulation results under the condition of single jammer



(a)



(b)

Fig 4 Time domain glide correlation results (multiple jammer)

Fig. 3(a) and Fig. 4(a) is the glide correlation simulation result. By using this mitigation method, the peak of self correlation of weak signal is not evident. In Fig. 3(b) and Fig. 4(b) the peak of self correlation of weak signal is clearly noticed.

6 Conclusion

This cross correlation mitigation method uses constraints to modify the local generate code as to drive the cross correlation sequence to zero, the advantage of this method is that it does not require estimation of the strong signal amplitude and it partially independent of the data bit value. Simulation result shows this method can eliminate the interference of 75% at the cost of sensitivity loss of 0.28dB.

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(From P.4)

5 Conclusions

Along with the electric power organizational reform unceasingly thorough, the tendency of the transmission line management and the MIS‘s fusion and integration is more and more obvious, based onthe safety control characteristics of the electric power profession, MIS will be displayed its key role in the business management fully. Realizing the effective integration of specialized management of safety in production and the business management will be the advanced pattern of electric power information oriented great-leap-forward development. Moreover the electric transmission management information system based on GIS has these merits: the automation is high, the reliability is high, the data will renew quickly, the information content will be big which is advantageous to the resource’s optimized disposition, Therefore it will have the widespread application prospect in the electric transmission management.

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