A MULTI-FREQUENCY ACQUISITION ALGORITHM FOR A GNSS SOFTWARE RECEIVER

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ABSTRACT

Globalization and digitization of the economy increase the demand for fast and precise positioning services. Existing and new global navigation satellite systems (GNSS) add flexibility and adaptability to the list of requirements. To cope with these demands GNSS receivers have been built as software solutions. For software receivers satellite signal acquisition is a hard problem. In this paper we have focused on improving the efficiency of the acquisition in the receiver. The proposed method combines multiple frequency steps into a single one to acquire the satellites. By this means we reduce memory demand and the number of FFT/IFFT calculations for correlation calculation, which is crucial for the performance of a software receiver, in particular on an embedded platform. To eliminate the influence and ambiguity of the multi-frequency approach, we introduce a correction procedure after the basic acquisition process. In our approach we choose several candidate results to implement a more precise acquisition. Our experiments show that the multi-frequency acquisition method saves a significant amount of resources in the acquisition phase, even in a weak GPS signal environment.

Index Terms— GNSS;GPS; software receiver; signal acquisition; multi-frequency acquisition; weak signal

1. INTRODUCTION

Positioning services are nowadays widely used, e.g. for car navigation or location-based services on smartphones. The internet of things [1] with billions of objects connected to the internet will further increase the use of such services. The globalization of economies in combination with the internet of things leads to connected objects moving around the systems (GNSS) GPS [2] and GLONASS [2] as well as the upcoming systems BeiDou [2] and Galileo [2] on one hand and the development of the internet of services [3] on the other hand flexibility and adaptability are desired features of a GNSS receiver that can be achieved by implementing it in software instead of hardware.

When regarding the architecture of a GNSS receiver, signal acquisition and signal tracking are the components that require the biggest share of resources in terms of computation and memory. Acquisition in general makes up of about 25 percent of the resources.

In recent years, many efforts have been spent on weak GNSS signal acquisition [3-7]. Most of them focus on how to increase the length of navigation data and how to predict the data bit transit of a GPS signal. In a weak signal environment, the acquisition uses longer bit sequences of navigation data which is a heavy burden for the software receiver and the performance of acquisition is unsatisfactory, especially when running on an embedded system. Based on fundamental acquisition methods and theory, we introduce a new weak GPS signal acquisition method which reduces fast Fourier transform/inverse fast Fourier transform (FFT/IFFT) calculations and memory effectively in the acquisition.

A common approach[3] uses a coherent/non-coherent acquisition method between the input signal and local signal replicas. To deal with a longer input signal in a weak signal environment, the acquisition uses high frequency resolution that means more FFT/IFFT calculations. To reduce FFT/IFFT calculations and time consumption, we combine multiple frequency steps into one frequency step to process acquisition and to determine whether the satellite is visible.

The rest of the paper is organized as follows. In a first step we discuss existing approaches for the acquisition of weak GPS signals. Then we describe the signal model. In a third step we present our model followed by a performance analysis. The paper closes with a summary of results and an outlook to future work.

2. ACQUISTION OF WEAK GPS SIGNALS

Coherent/Non-coherent acquisitions are common methods in a software receiver. They process the received signal and locally generated replica with circular correlation based on FFT/IFFT. In a weak GPS signal environment, a software receiver uses longer coherent and non-coherent integrations to increase the sensitivity of the acquisition. However, there is a navigation data transition every 20 ms; thus, the length of coherent integration is limited [3]. As a consequence, a common maximum length used for weak signal acquisition is 10ms to avoid the transition of navigation data. Several other methods have been proposed in the literature to increase the sensitivity of acquisition. The half-bit alternation method, full-bit alternation method[4] or CCMDB (Circular Correlation with Multiple Data Bits)[5] are used to increase the length of coherent integration and avoid the effect of a transition of navigation data. DBZP (Double Block Zero Padding) [5], MDBZP [5] (Modified Double

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Block Zero Padding) and FMDBZP [6] (Fast Modified Double Block Zero Padding) improve the efficiency of the acquisition based on P-Code acquisition technology. [7] introduces a new method that uses folding and sub-sampling techniques in FFT/IFFT. Most of the methods focus on avoiding the effect of the transition of navigation data with longer signals received. However, the performance of acquisition still remains a problem for a software receiver. To solve this issue our proposed method focuses on decreasing calculations based on multi-frequency acquisition.

2.1. SIGNAL MODEL AND ACQUISITION

The GPS civil signal L1, which is 1575.42 MHz with C/A code, can be described by the following expression:

$$S_{L1}(t) = A \times D(t) \times C(t) \times \mathrm{e}^{j(2\pi f_d t + \varphi_0)} + N(t) \quad (1)$$

where A is the amplitude of the L1 signal, $f_c = 1575.42$ MHz is the frequency of the L1 signal, f_d is the Doppler frequency shift and $f_d \in [-5\text{kHz}, +5\text{kHz}]$. $D(t)$ is the navigation data, $C(t)$ is the C/A code, and $N(t)$ is noise.

The acquisition module searches the matrix and finds out the peak value as shown in Fig.1. If the peak value exceeds the threshold, it means this satellite is visible; otherwise, this satellite is invisible.

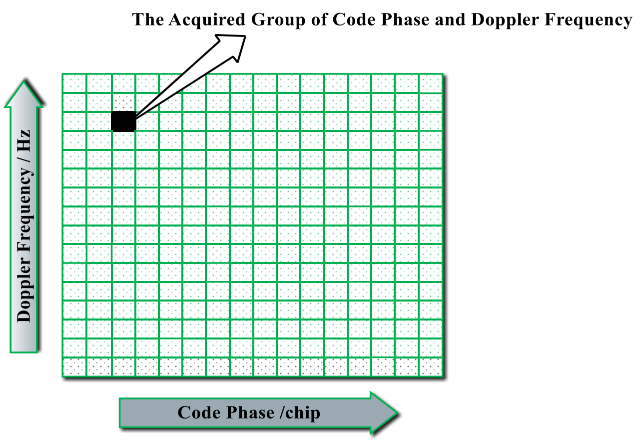


Fig 1. Two-dimensional search matrix

3. THE MULTI-FREQUENCY ACQUISITION (MFA) METHOD

In the acquisition, the number of local replicas is determined by the length of navigation data. Especially, in a weak GPS signal environment, the software receiver increases the length of navigation data to increase the sensitivity of the acquisition. However, a longer received signal means a higher resolution which implies more FFT/IFFT calculations. Obviously, the increased FFT/IFFT calculations imply more calculation time and higher memory demands for the acquisition.

To reduce the calculation time and the memory demands for the acquisition, our MFA method combines multiple frequency steps into one frequency step, i.e. we choose several frequency steps as one new frequency step, instead of using single frequency steps in the FFT/IFFT calculations. The acquisition module implements FFT/IFFT calculations with these new frequency steps and determines the final result.

The received signal multiplies with the local multi-frequency replica which is expressed as:

$$y(t) = A_i \times D_i(t) \times C_i(t) \times \cos(2\pi(f_{IF} - f_{d_i}) + \varphi_i) \times C_i(t) \times (\cos(2\pi \hat{f}_{ij} t + \hat{\varphi}_i) + \cos(2\pi \hat{f}_{ik} t + \hat{\varphi}_i)) \quad (2)$$

This expression shows that the correlation result for the ith satellite. φ_i is the real phase and $\hat{\varphi}_i$ is the estimated phase. f_{d_i} is the Doppler frequency shift in the received signal. $\hat{f}$ is the locally estimated frequency. The local multi-frequency replica combined with two local signals with different estimated frequencies $\hat{f}_{ij}$ and $\hat{f}_{ik}$, $\hat{f}_{ij}, \hat{f}_{ik} \in \{\hat{f}_{i1}, \hat{f}_{i2}, \ldots, \hat{f}_{im}\}$ $m = 10000/s$, where m is determined by the frequency step s.

The frequency step is closely related to the length of the navigation data used in the acquisition. From [3] we know that when the input signal and the locally generated signal are off by 1 cycle, there is no correlation. It is arbitrarily chosen that the maximum frequency separation allowed between the two signals is 0.5 cycle. After the coherent integrations, the power of the output signal is

$$P_{output} = P_{input} \times T_S^2 \times \mathrm{sinc}^2\left(\frac{\pi \Delta f T_S}{2}\right) \quad (3)$$

where P_{input} is the power of the input signal, T_S is the length of the coherent integration and Δf is the frequency error. Fig.2 illustrates the relationship between the powers of the output signals and the frequency error with different integration periods.

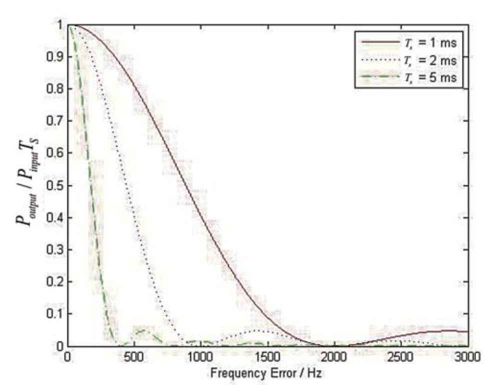


Fig.2 Frequency error on the acquisition ability

As shown in Fig.2, the rate of power attenuation increases effectively as the time period of integration increases. So our proposed method considers the locally generated replicas with a large frequency error which exceeds one frequency step as noise. With longer length of the coherent integration, the large frequency error has limited influence on the correlation as noise. Although the MFA method reduces the amount of the FFT/IFFT calculations in the acquisition, there is still the problem that the local replicas with multi-frequency would increase the energy of noise. The expression of coherent integration is

$$
\begin{aligned}
y(t) &= A_i \times D_i(t) \times C_i(t) \times \cos(2\pi(f_{IF} - f_{d_i}) + \varphi_i) \times \\
&\quad C_i(t) \times (\cos(2\pi \hat{f}_{ij}\, t + \hat{\varphi}_i) + \cos(2\pi \hat{f}_{ik}\, t + \hat{\varphi}_i)) \\
&= A_i \times D_i(t) \times C_i(t) \times \cos(2\pi(f_{IF} - f_{d_i}) + \varphi_i) \times \\
&\quad C_i(t) \times \cos(2\pi \hat{f}_{ij}\, t + \hat{\varphi}_i) + \\
&\quad A_i \times D_i(t) \times C_i(t) \times \cos(2\pi(f_{IF} - f_{d_i}) + \varphi_i) \times \\
&\quad C_i(t) \times \cos(2\pi \hat{f}_{ik}\, t + \hat{\varphi}_i) \\
&= A_i \times D_i(t) \times C_i(t) \times \cos(2\pi(f_{IF} - f_{d_i}) + \varphi_i) \times C_i(t) \times \\
&\quad \cos(2\pi \hat{f}_{ij}\, t + \hat{\varphi}_i) + N_{new}
\end{aligned}
\tag{4}
$$

where N_{new} denotes the correlation results of the local replica with large frequency error as the new noise. The MFA method would increase the energy of noise and decrease the sensitivity of the acquisition. To eliminate this ambiguity, we apply a correction step to correct or identify the results of the multi-frequency method, as shown in Fig.3.

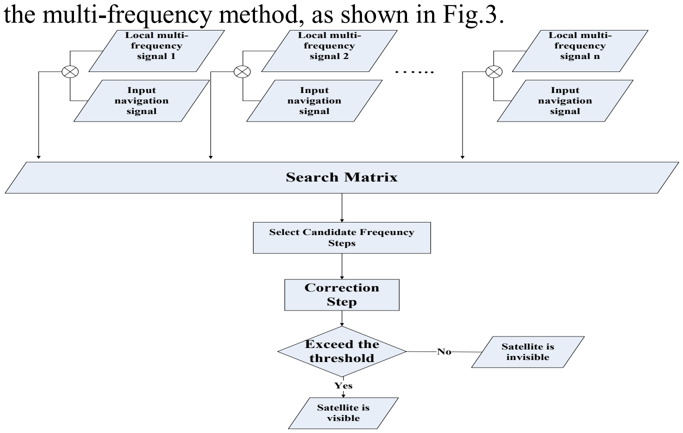


Fig.3 The MFA process

The approximate frequency should lie in the range of the combined frequencies and is identified by the MFA method as the peak result. The correction step selects several combined frequencies by using the peak values. The selected combined frequencies are divided into two single original frequency steps. The correction step applies FFT/IFFT again to these replicas with single frequencies separately. Finally, it determines which satellite is acquired successfully depending on the new results.

4. PERFORMANCE OF THE MFA METHOD

We use matlab (version 7.0.1) for simulating our proposed method. The program runs on a laptop (Intel CPU i5-3337U, 1.8 GHz; 4 GB memory) under the Windows 8 operating system based. As matlab allows to control the simulated signals and to modulate noise with special energy easily, we use matlab to simulate the input signals in our experiments. The frequency of the generated data is 50 MHz, and the frequency of the C/A code is 1.023 MHz.. We set 12 satellites to be visible. The simulated input signal is sampling at 6.144 MHz and modulated noises with different energy levels are added.

On this platform the acquisition using the generated signal roughly takes between 20 and 70 seconds, depending on the length of navigation data (c.f. fig. 4). The acquisition based on the recorded signal takes basically the same time.

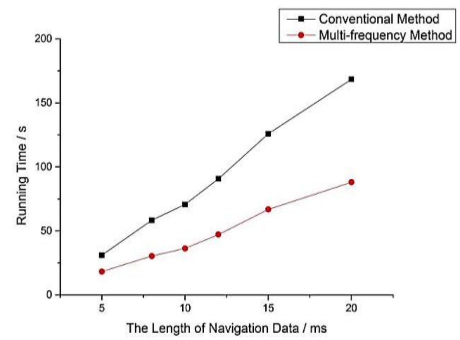
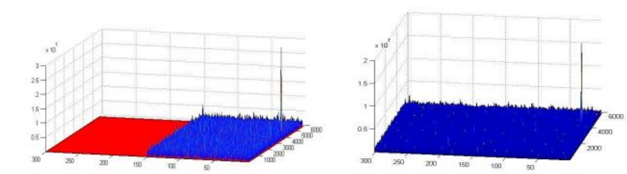


Fig.4 Computing time of signal acquisition

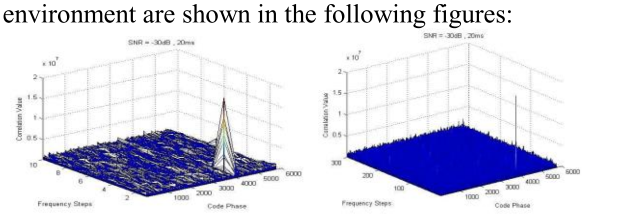
Comparing with a conventional method, the MFA method could reduce about 50% FFT/IFFT calculations and narrow the searching range. In Fig.5, the left red part shows the saved memory which is about 50% of a conventional search matrix.



(a) MFA searching range (b) Conventional searching range

Fig. 5 Two searching ranges

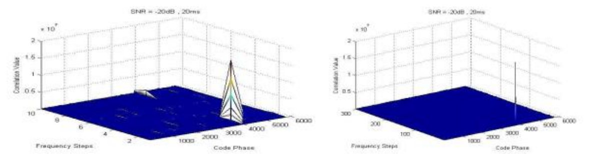
The results of our experiments for a weak signal environment are shown in the following figures:



(a)MFA method for weak signal (b)Conventional method for weak signal

Fig. 6 The results of two methods for weak signals

In a strong signal environment, both methods could gain good results, even the MFA method without correction step to deal with the ambiguous frequencies.



(a)MFA method for strong signal （b）Conventional method for strong signal

Fig. 7 The results of two methods for strong signals

In Fig.6 and Fig.7, we could find that after the correction step, the MFA method achieves the same output value as the conventional method and avoids the influence of power attenuation in the former multi-frequency procedure. Compared to conventional methods, the time consumption of our multi-frequency method is obviously reduced. Fig.8 depicts the amounts of FFT/IFFT calculations of a conventional method and of our approach for different lengths of navigation data.

Fig.9 illustrates the performance of these methods for different lengths of navigation data. Our MFA method saves about 40% of acquisition time.

As our MFA method uses combined frequencies, the acquisition creates a search matrix with half of the original memory demand for the acquisition, which is also important for a receiver on an embedded system.

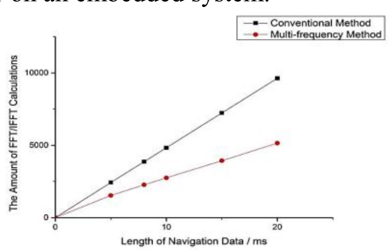
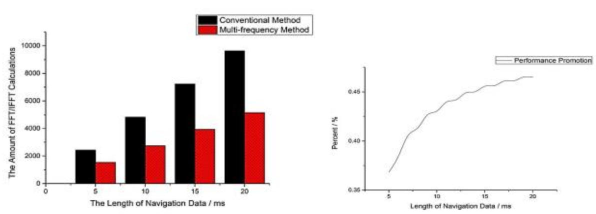


Fig. 8 Comparison of FFT/IFFT calculations



（a）The comparison of two methods （b）Performance improvement

Fig .9 Performance comparison of two methods

5. CONCLUSION

Our experiments show that the multi-frequency acquisition (MFA) method could be used for the acquisition of a weak GNSS signal. In a strong or weak signal environment, the MFA method achieves good acquisition results with high efficiency and small memory footprint in the software receiver. As the length of navigation data increase, this method still improves the performance of the acquisition efficiently.

We have transferred our acquisition module onto a Raspberry Pi Model B under Raspbian. The result shows that it is possible to implement a software receiver on a low cost embedded system. Currently, the speed of the software receiver is sufficient for slow moving objects in larger geographic areas (e.g. container at a container terminal). Performance is still behind expectations but the development speed of embedded systems makes it very likely that our results become applicable in the near future.

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