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FAOSIGNAL ACQUISITION FOR SOFTWARE-DEFINED GPS RECEIVER

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Abstract

Signal acquisition plays important role in the estimation of navigation solutions as precise values of code phase and carrier frequency yield more accurate results in positioning systems. Software-defined radios are computationally expensive so we need the solution to reduce the time complexity and processing power. In this paper, we have described and demonstrated the parallel code phase search acquisition method for software-defined GPS by using python. We have compared the computational requirements of the implemented method and other signal acquisition methods. The experimental result shows the difference between the acquisition output of the visible PRNs and invisible PRNs.

Keywords:

Acquisition, code phase parallel search, correlation, FFT, GPS

1. INTRODUCTION

The cold war between USA and USSR was the seed of the modern Satellite navigation systems [1]. The research on satellite navigation had started in 1957 when the Soviet Union launched Sputnik I satellite [2]. Scientists across the whole world initiated their research in understanding earth science from a different perspective. Almost every country rushed into the space race to design the most efficient satellite communication technology. This race ultimately encouraged the researchers to design the satellite navigation system. In 1960 US Navy launched the world's first navigation system called Transit or NAVSAT [3]. However, satellites were primarily designed for military purposes only to locate submarines and surface ships. In 1973 US military started designing a comprehensive worldwide navigational system called as Global Positioning System (GPS).

In 1983, the US government made the GPS available for civilian use. Later in 1989, Magellan Navigation Inc. designed the world's first commercial handheld GPS receiver NAV1000. After that, in recent decades, the world has witnessed the technology evolution in GNSS systems and receivers, today, there are at least 24 operational GPS satellites providing the navigation service. European Union, China, Russia, India, Japan have launched their GNSS systems and almost every smartphone has a GNSS receiver installed in it. Researchers are still working on improving the accuracy of these navigation solutions.

The basic principle of the GNSS receiver is derived from the formula for speed. i.e., speed = distance/time. If we know, the time required to arrive the signal from a satellite to a receiver (Time of arrival – Time of transmission), then we can calculate the distance between satellite and receiver (speed of the signal is close to the speed of light), and by combining the solutions provided by multiple satellites (Min. 4), we can estimate the exact location of the receiver [4]. To find the navigation solution, first, we need to extract the navigational information from the received signal. To decode the data, we need two important parameters, the code phase of the received signal and the frequency of the carrier.

The process of determining the visible satellites and precise values of carrier frequency and code phase of the signals received from the satellite is known as GNSS signal acquisition. Navigation satellites are distinguished by the 32 unique pseudo-random noise (PRN) codes. While the code phase is used to determine the time indentation of the PRN code in a received signal. There will be a higher correlation between the locally generated signal and the incoming signal if the lag between the two signals is zero.

Carrier frequency (in the case of down-conversion it is equal to an intermediate frequency (IF)) can be estimated from L1 carrier frequency and mixers in the converter. But due to the doppler effect, it gets deviated from the expected frequency value. To eliminate the carrier wave from the GPS signal, it is necessary to know the precise value of carrier frequency. So, carrier frequency estimation and code phase estimation are important tasks in finding navigation solutions. So, the process of signal acquisition is important in all the GNSS systems. But the main problem in signal acquisition algorithms is time complexity. So many researchers are still working on improving the performance of the algorithm.

Software-defined radios (SDR) are modern receivers that have strong potential to replace traditional hardware-based architecture which consists of amplifiers, mixers, filters, modulators, demodulators with software-based architecture [5]. Every signal-processing component in the receiver can be implemented by using software with any general-purpose microprocessor without any requirement of the specialized hardware component. This SDR technology is evolving rapidly due to the capability of embedded systems of rendering almost every signal processing component. This receiver only needs one hardware called Radio Frequency (RF) front-end that receives the signal, down converts it to an intermediate frequency, and stores it in the digital form (Byte array). These byte arrays then can be processed with the help of software programs to get the required information.

Borre et al. [6] proposed the method to design and implement the GPS receiver by using software-defined radio titled as Software-Defined GPS receiver. This receiver completely replaces the traditional hardware-based receiver with the computer program. Though the software-based receiver is less efficient than the hardware-based receiver in terms of computational power, it provides huge flexibility to both developers as well as the user. Any customizations or modifications can be done in the receiver as per the user requirement, as it won't need any specialized hardware. Also, updates can be released and can be installed easily compared to upgrading hardware-based architecture. Likewise, software-based receivers are less expensive than hardware-based receivers.

2. RELATED WORK

For the high orbit space, Kewen, et al. [7] developed a novel GPS signal acquisition technique. The propagation mechanism of the GPS signal link is used to study the properties of high orbit GPS signals. The impact of cross-correlation interference (CCI) on side lobe signal acquisition performance is investigated. To improve acquisition sensitivity, the coherent and incoherent accumulation are coupled using the parallel code phase search method. At the same time, CCI is detected using hypothesis testing based on the auto-correlation and cross-correlation peaks in the correlator output having different probability distribution characteristics. To reconstruct the strong signals, the tracking loop's amplitudes, code phases, and Doppler shifts are used.

Guodong et al. [8] presented a CS-based GPS signal collection method in their paper. The GPS sparse signal is recovered using the matching pursuit algorithm. The approach can effectively recover the GPS sparse spike signal, according to numerical simulations. Compressive sensing in GNSS is restricted to GPS with SMV, while compressive sensing in GLONASS with MMV has yet to be described.

Sun et al. [9] designed a GPS signal rapid acquisition system in FPGA utilizing the extended multiple correlator method. In a 12-channel GPS signal collection system, an extra noise-monitoring channel is used to provide an adjustable threshold. The results of programming the system on an FPGA development platform show that it can gather GPS signals faster and with less effort than standard receivers. The author's invention has a lot of practical usefulness; it can be used in a GPS receiver right away, and it can also be utilized in other direct sequence spread spectrum receivers.

Qiu and Lei [10] proposed the method of GPS signal acquisition by using the FFT algorithm. The local test signal's Doppler frequency value is gradually modified, and the received signal is demodulated. All of the delay values in a single shot are evaluated using the FFT property.

A cosmological study is performed at parallel frequencies in the paper presented by Haj et al. [11]. Radio Defined Software (SDR) technology is used to implement the GPS (Global Positioning System) receiver algorithm. The proposed method is practically implemented and tested on the MyRio real-time software processor platform from National Instruments. Using implementation platforms, the proposed algorithm's results are validated and compared to a parallel cipher phase search algorithm. Searching for frequencies in parallel Recommended for high throughput and real-time applications. Transparent application in product development and industry platforms where low cost, low complexity, and consistent performance are critical.

Qingxi et al. [12] presented results based on an equal recurrence search calculation. When the estimated period of Pseudo-Random Noise (PRN) code and the inexact worth of a Doppler shift are known, the Parallel Frequency space search securing Calculation (PFA) is faster than the Parallel Code stage search securing Algorithm (PCA). Regardless, the Quick Fourier Transform (FFT) in a standard PFA calculation should have handled a lot of data because it processes a limited band signal with the underlying examining recurrence after the PRN code is stripped. A down-change module and a downsampling module were added to the traditional PFA calculation in the work announced to reduce the computational complexity of the traditional PFA calculation.

In the paper presented by Wu et al. [13], the author describes the acquisition in the time domain using the serial method. Cells searched in serial seek to Check disk space cell by cell for unknown delay And Doppler frequency values. The incoming data is multiplied by the PRN code chip Copies A local check signal is generated for this purpose. This is correlated with the input signal. delay Doppler frequency value of test signal Gradual change in the search space cross ambiguity function (CAF) is evaluated for the presence of satellite. If no signal is found, the acquisition will continue with Different Doppler frequency slices. After checking everything Possible, no successful result was achieved the system will change the satellite we are searching for.

3. METHODOLOGY

While developing GNSS receivers, especially software-defined GNSS receivers, it is necessary to optimize the computational power and time complexity of the signal acquisition algorithm. The basic idea of signal acquisition is we iterate over the combinations of carrier frequencies and code phases, and we compute the correlation between locally created signal and the received signal. The values for which we get the high correlation, are then used to acquire or decode the navigational data. So, in this searching algorithm, we need to iterate over all feasible carrier frequencies in the range of IF-10kHz and IF+10kHz in the step of 500 Hz (as due to the Doppler effect, maximum deviation could be ±10kHz) and all 1023 code phases. So, we need to iterate over 10000 by finding the peak in obtained correlation (if present), we can estimate the code phase of the incoming signal.

3.1 PARALLEL SEARCH METHOD

This is a very high number in terms of time complexity and computational power. It would take a lot of time to do this search for 32 satellites. This search algorithm can be implemented easily with the serial search method, but it would not be computationally efficient. So, we need to parallelize this search operation either by parallelizing frequency space search or by parallelizing code phase space search. If we parallelize the frequency space search, ultimately the requirement of iteration over 41 values of frequencies would be eliminated. So, we need to search through only 1023 combinations. It would reduce the time complexity of an algorithm to some extent. But instead of parallelizing the acquisition algorithm in frequency space, if we could parallelize it in code phase dimension, we only need to iterate over 41 combinations. Which could be an efficient way to estimate the code phase and carrier frequency of a signal.

3.2 PARALLEL CODE PHASE SEARCH ALGORITHM

In signal acquisition, we need to accomplish the correlation between the incoming code and the generated PRN sequence. In the serial search method, we perform multiplication between the incoming code and PRN code with 1023 code phases. Instead, we can perform a circular cross-correlation between incoming code and PRN sequence without shifting the code phase to reduce the computational complexity. After circular cross-correlation, we need to transform the frequency domain representation to time-domain representation. This can be done by performing inverse Fourier transform. Fig. 1 describes the parallel code phase search algorithm for a single satellite. Signal I is obtained by multiplying the original signal with the local carrier signal generated by the oscillator and signal *Q* is obtained by multiplying the original signal with a 90° phase-shifted version of a local carrier signal. Then signal I and signal *Q* are mixed to form a complex signal $X(a) = I(a)+jQ(a)$ and parsed to the Fast Fourier Transform (FFT) function to compute discrete Fourier transform (DFT). PRN code generator generates the local PRN code, then the DFT of the PRN code is computed to transform it into the frequency domain. After computing the DFT, its complex conjugate and the previously calculated Fourier transform of $x(a)$ is multiplied. Then the result of the multiplication is parsed to the Inverse Fourier transform function to get the time domain representation. The absolute value of its result is the correlation between the input signal and the PRN code.

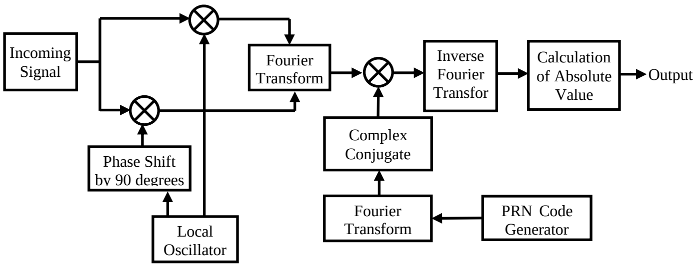

Fig.1. Block diagram of the parallel code phase search algorithm

4. IMPLEMENTATION

We have implemented the parallel code phase search algorithm by using python. As python has huge library support, it is easy to develop the program rather than any other programming language. We have utilized the NumPy library.

The Fig.2 illustrates the flow diagram of the signal acquisition program. First, we need to reallocate the arrays required for storing the results. Then the local PRN sequence for a specific satellite can be generated. The further processing will be similar as mentioned before. After getting results for a specific satellite, if the magnitude of the peak is greater than the acquisition threshold (in our case 2.5), then we can consider the presence of a GPS signal. Then the precise value of carrier frequency is estimated via DFT and all the results along with the acquisition metric are recorded. Then the program repeats the whole process for the next satellite. After testing all the PRN codes, results are displayed.

5. RESULTS

For experimentation, we have used the dataset curated by the authors in [10]. Authors have used the stereo front-end developed by Nottingham Scientific Ltd. To capture the signal. The sampling frequency of the front end was 26 MHz and the intermediate frequency was 6.5MHz. The Fig.3 shows the time-domain representation of the input received from the RF front end and Fig.4 shows the frequency domain representation of the input.

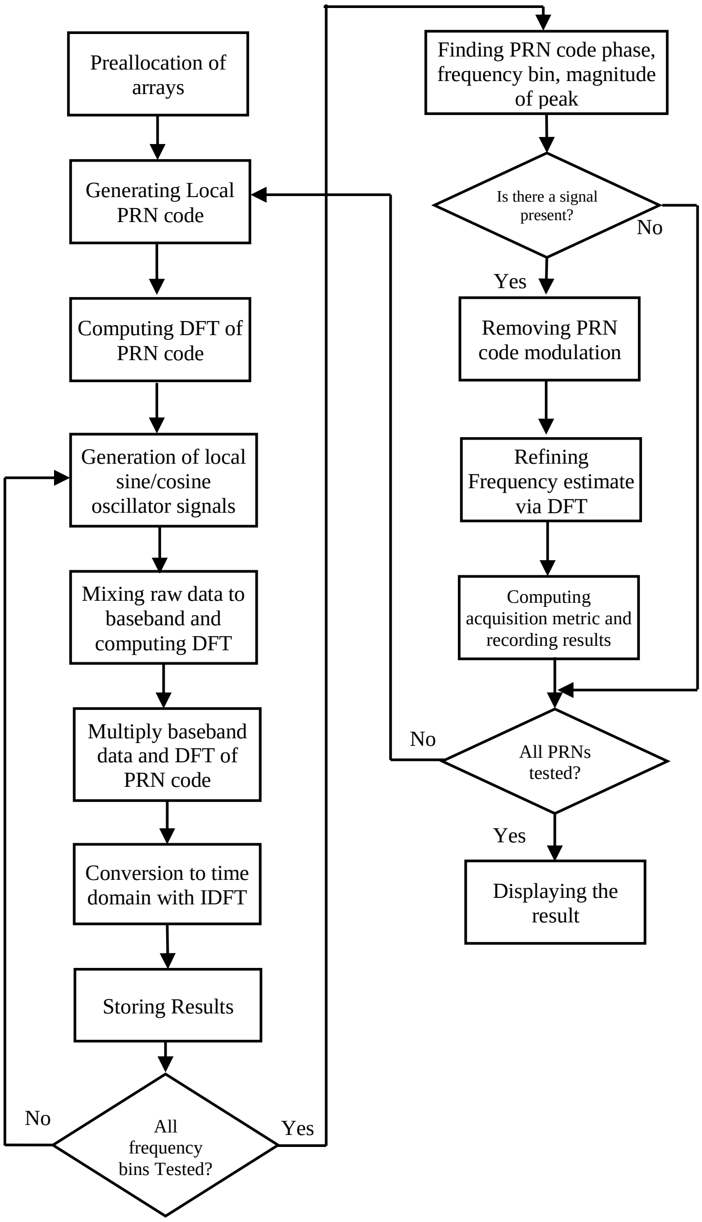

Fig.2. Flow diagram of the signal acquisition program

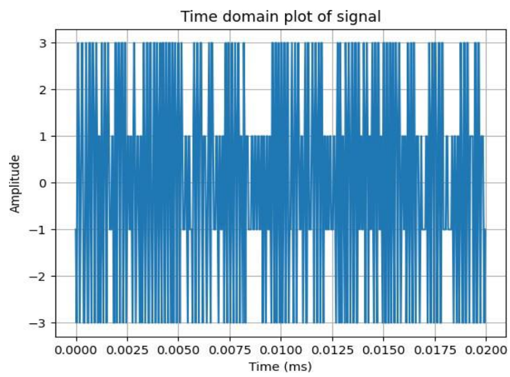

Fig.3. The time-domain plot of the input signal

Output from parallel code phase search acquisition for each satellite (different PRN codes) are dumped and plotted at each stage. The Fig.5 illustrates the correlation between the input signal and locally generated codes corresponding to different PRN codes. We can observe that the significant peak is only present in Fig.5(3), Fig.5(4), Fig.5(7), Fig.5(9). i.e. Only PRN 10, PRN 12, PRN 20, and PRN 32 are visible. In the case of other satellites, as the peak is not present in correlation, we can assume that the corresponding satellite is not visible. We should record the data only for those satellites for which a significant peak in correlation is present.

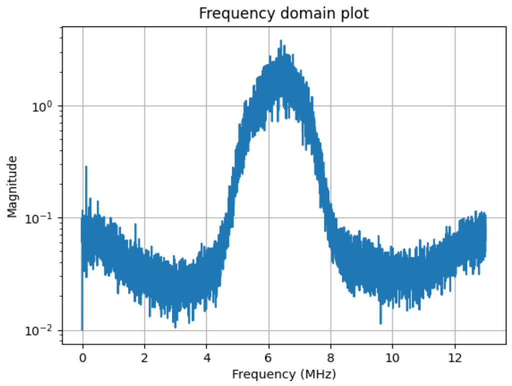

Fig.4. Frequency domain plot of the input signal

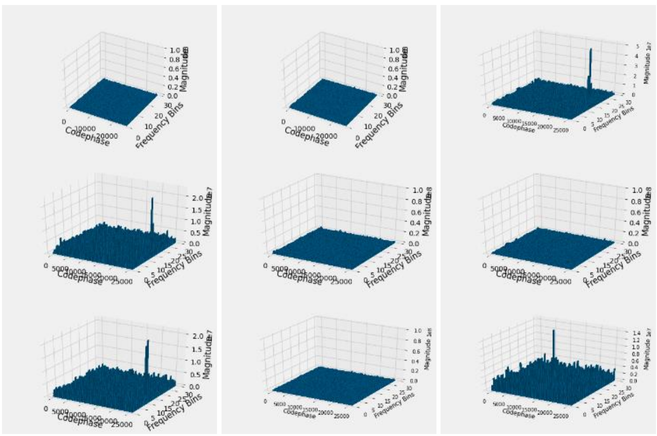

Fig.5. Output obtained from parallel code phase search acquisition shows the correlation between input code and generated code.

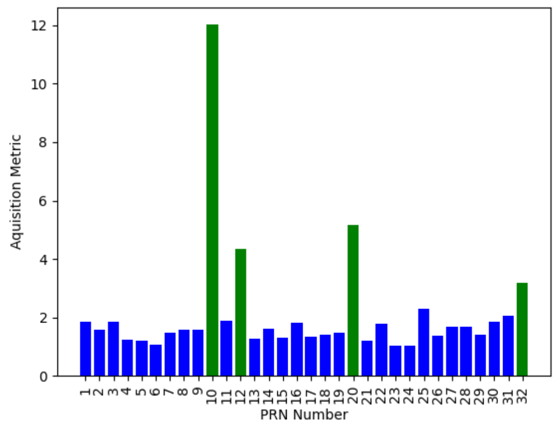

Fig.6. Signal Acquisition Results. (x-axis: PRN number, y-axis: Acquisition Metric)

The Fig.6 shows the acquisition metric for every PRN code. We can observe that the acquired PRN codes have acquisition metrics greater than the acquisition threshold (2.5). Acquired values of carrier frequency and code phase corresponding to each acquired satellite are shown in Table.1.

Table.1. Signal Acquisition Results

PRN	**Carrier Frequency**	**Doppler**	**Code Phase**
10	6502913.475	2913.475	21638
12	6500979.424	979.424	23672
20	6500743.866	743.866	22331
32	6502491.951	2491.951	10269

6. CONCLUSION

Software-defined GPS receivers provide a lot of flexibility in terms of development and use cases. We can implement every signal processing component in software and it encourages researchers to improve the accuracy and speed of receivers. From this research, we have concluded that the parallel code phase search acquisition algorithm is comparatively faster and computationally less expensive than serial search acquisition as well as parallel frequency space search acquisition

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