PARALLEL ALGORITHMS FOR DIGITAL PROCESSING OF GEOPHYSICAL SIGNALS

Ibragimov Sanjarbek Salijanovich
t.f.f.d. (PhD), Andijan State Technical Institute
email: sanjari07@yahoo.com

Abstract
This article presents the development of parallel computational approaches for spectral analysis based on two-dimensional fast Haar transform algorithms in the digital processing of geophysical signals. The study analyzes the processing of signals obtained through magnetometry, gravimetric, and electrical prospecting methods using spline functions and the Haar transform. A parallel computing technique based on bipolynomial basis functions and fast transform algorithms was developed and implemented on ADSP-BF533 and BF-561 processors, with a comparison of their computational speeds. The results demonstrate that dual-core processors achieve significantly higher performance compared to single-core processors.

Keywords: Haar transform, geophysical signal, parallel computation, spline function, bipolynomial basis, acceleration factor.

Introduction

Geophysical research is one of the most important scientific and technical fields in the exploration of subsurface resources and the detection of physical anomalies. Through methods such as magnetometry, gravimetric surveying, electrical prospecting, and electromagnetic exploration, large volumes of digital signal data related to the Earth's physical fields are obtained. In analyzing these signals, spectral methods and digital transformation algorithms—particularly the Haar transform—are widely applied. However, real-time analysis of large-scale geophysical signals demands substantial computational power. Therefore, the development of parallel computing algorithms has become a critical issue [1,5,7-10].

This article focuses on the spectral analysis of two-dimensional geophysical signals based on Fast Haar transforms, the development of parallel computing algorithms utilizing bipolynomial basis functions, and the evaluation of their performance on single-core and dual-core processors.

Metadology

In geophysical research, samples are often collected from the study area using gamma-ray radiometers, ground-based magnetometers, geoelectric sensors, or induced electromagnetic sensors to search for certain anomalies. Additionally, gravitational, electrical, and magnetic prospecting methods are employed for the exploration of subsurface mineral resources. The magnetometric surveying method utilizes instruments such as magnetometers to measure the parameters of the Earth's surface magnetic fields. This approach enables the detection of anomalies associated with the absence or variation of magnetic fields. Magnetometric surveys can be conducted via airborne methods (i.e., using airplanes or helicopters), covering extensive areas spanning hundreds of square kilometers [5,6,8].

In subsurface resource exploration, gravitational, electrical, and magnetic prospecting methods are widely used to analyze variations in the Earth's gravitational, electric, and magnetic fields. These methods facilitate the discovery and identification of valuable mineral deposits and associated structures.

Multiple exploration techniques are often combined to enhance each other's effectiveness. For instance, magnetic surveying can be complemented by electrical prospecting methods, thereby aiding in the detection of different types of physical anomalies within the Earth's structure. Magnetometers, gamma-ray radiometers, and geoelectric sensors are among the most sensitive and effective tools compared to other surveying methods. Moreover, these methods are versatile and applied for a variety of exploration objectives.

The application of mathematical methods is of great significance in solving geophysical problems. Spectral analysis and spline-based methods are among the most widely employed techniques in this field.

Spectral analysis is a comparative and independent method used to study the characteristics of geophysical objects. It provides information about the spectrum, spectral components, and spectral directions of geophysical phenomena. Spectral analysis plays a crucial role in identifying the structure of geophysical objects and monitoring their variations over time [11].

In the digital processing of two-dimensional geophysical signals, spectral analysis based on two-dimensional fast transforms is utilized to obtain information about subsurface structures, the distribution of oil and gas reserves, and to detect anomalies in the Earth's magnetic fields caused by the presence of mineral deposits.

In the processing of real multidimensional signals, models are often employed that operate based on spatial domain rather than spectral domain. Under such conditions, spline function methods are more suitable for selecting the optimal measurement step size [9].

The amplitude spectrum of a finite system of two-dimensional orthogonal B-splines of degree *m* approximating the function f(x,y) is expressed as follows [8]:

$$F_{\sum B}\left(\omega_x,\omega_y\right)=F_{B0,0}\left(\omega_x,\omega_y\right)\times\left|\sum_{i=0}^{n_1}\sum_{k=0}^{n_2}b_{ik}\exp\left(-ji\omega_x\left(m+1\right)h_x\right)\exp\left(-ji\omega_y\left(m+1\right)h_y\right)\right| \quad (1)$$

Here ω_x, ω_y are spatial frequencies;

$F_{B0,0}(\omega_x, \omega_y)$ – is the initial B-spline spectrum;

h_x, h_y – represent the distances between the node points forming the discrete steps along the x-axis and y-axis, respectively.

The spectrum of the initial B-spline is calculated according to the following formula:

$$F_{B0,0}\left(\omega_x,\omega_y\right)=Ah_xh_y\left(\frac{\sin\left(\omega_xh_x/2\right)}{\left(\omega_xh_x/2\right)}\right)^{m+1}\left(\frac{\sin\left(\omega_yh_y/2\right)}{\left(\omega_yh_y/2\right)}\right)^{m+1} \quad (2)$$

Here, $F_{B0,0}\left(\omega_x,\omega_y\right)$ denotes the amplitude of the initial B-spline.

Analysis and Results

To enable real-time digital processing of two-dimensional geophysical signals measured by electromagnetic methods from the Earth's surface, we developed a parallel computation algorithm based on the amplitude spectrum of a finite system of B-splines using the Fast Haar transform on the dual-core Blackfin ADSP-BF561 specialized processor (Figure 1). The algorithm outlines the details of parallel operations executed by Core A and Core B. In this process, the formula for the amplitude spectrum of a finite system of orthogonal B-splines serves as the computational foundation. In particular, at the initial stage of Core B, the amplitude spectrum is calculated using formula (2).

Within the parallel algorithm, Core A and Core B perform distinct tasks. Core A initializes the data matrix and carries out Fast Haar transforms along rows and columns, preparing the signal for spectral analysis. Meanwhile, Core B computes the initial amplitude spectrum and performs spectral transformations in parallel. The transition between sequential and parallel computation modes is managed through the *State* parameter within the algorithm.

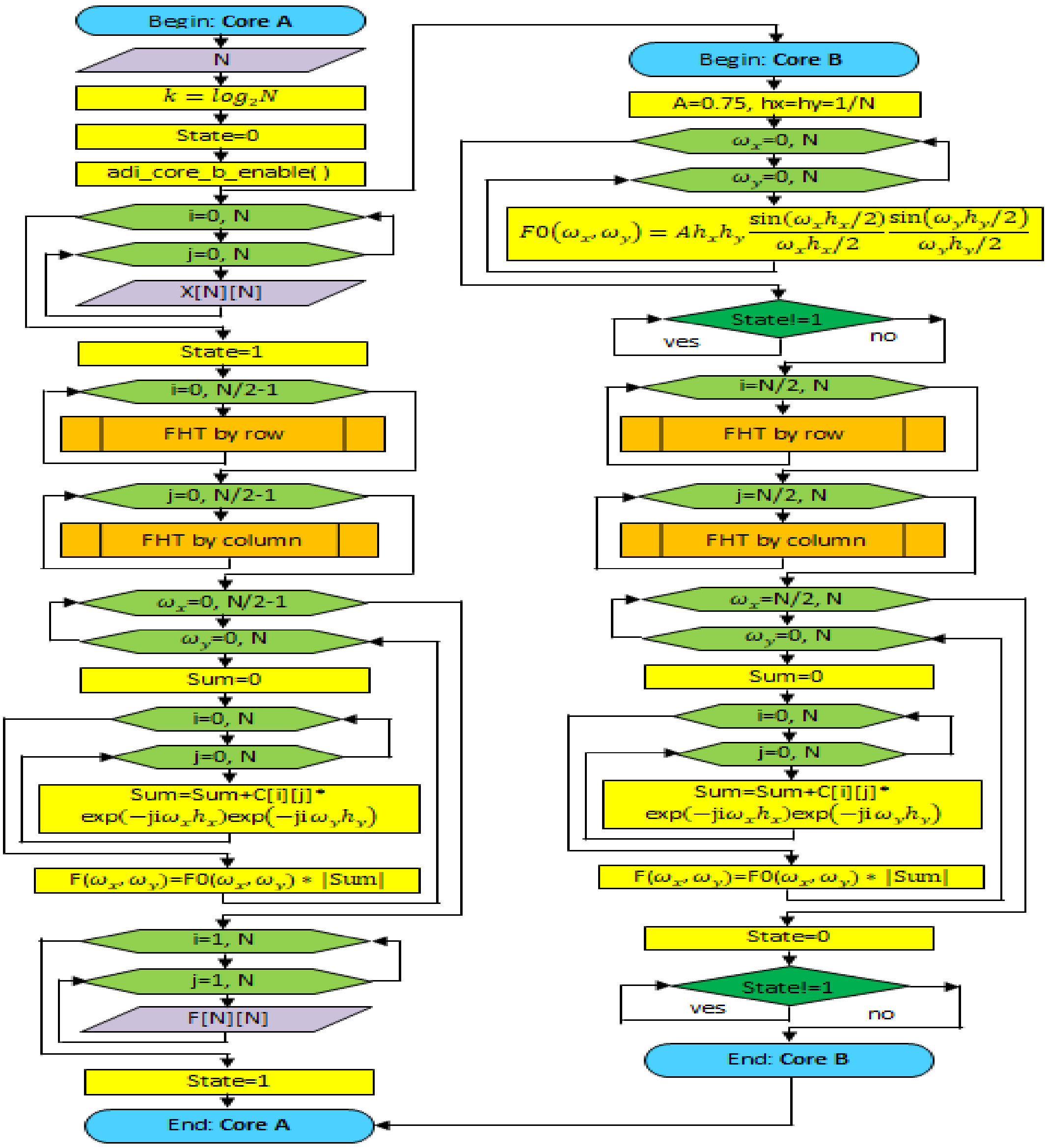

Figure 1. Parallel Computation Algorithm for Spectral Coefficients of Two-Dimensional Magnetic Field Signals

Figure 2 shows the distribution of magnetic field values measured using the aeromagnetic survey method at the Earth's surface. Each value was obtained during aeromagnetic measurements over a 15×15 km area, with a sampling interval of 1 km along the horizontal x and y coordinates.

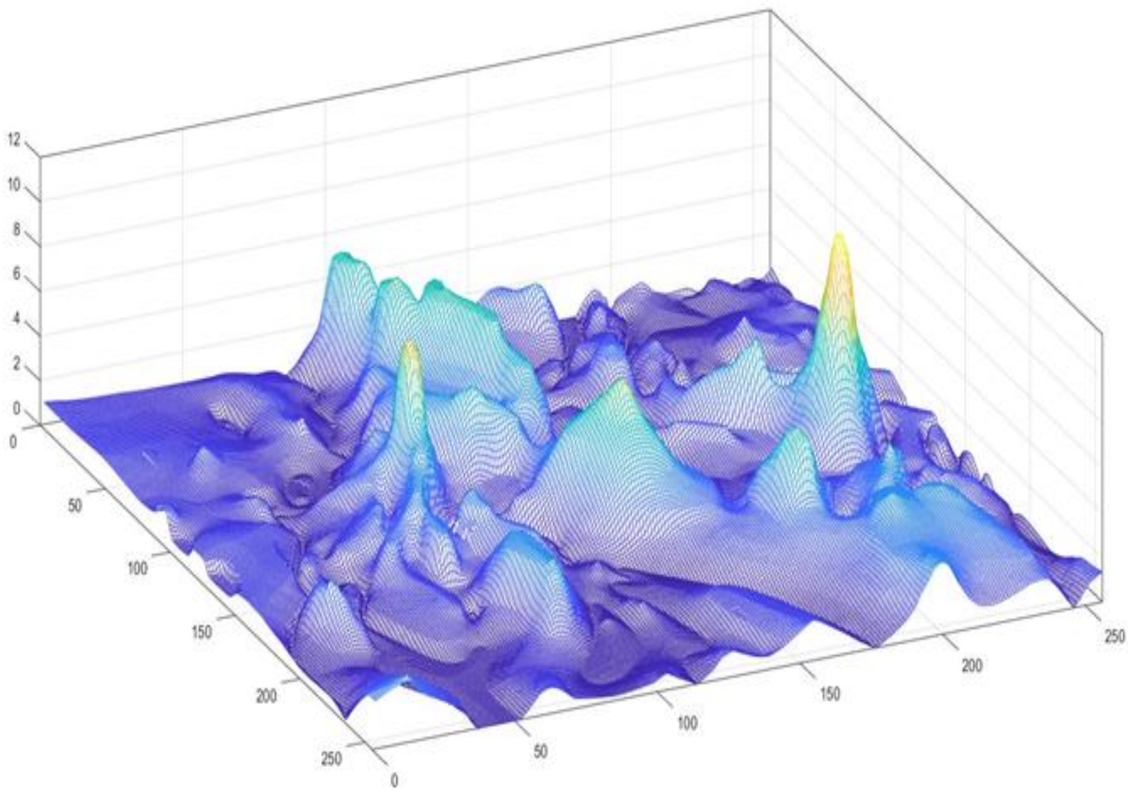

Figure 2. Graph of Electromagnetic Field Values Measured at the Earth's Surface

The prominent central peak represents the dominant spectral component, indicating that the majority of the signal's energy is concentrated in the low-frequency range. This suggests the presence of a large and stable magnetic anomaly in the subsurface structure. The smaller peaks surrounding the central one may correspond to finer structural variations or higher-frequency components embedded within the signal.

This amplitude spectrum is of critical importance in several respects:

- determining the energy distribution of the signal,
- identifying dominant frequencies for the detection and localization of geophysical sources, and
- assessing the performance and effectiveness of the implemented parallel algorithms.

Table 1 presents a comparison of the computation times for Fast Haar transforms based on bipolynomial bases on single-core and dual-core processors. Acceleration factors were determined based on the times required for sequential and parallel computations. As seen from the table, the dual-core processor required 1.52 to 1.86 times less computation time compared to the single-core processor. Specifically, when the two-dimensional signal size was 1024×1024, the acceleration factor reached 1.86.

Table 1. Comparing the Computation Times of Fast Haar transforms Based on Bipolynomial Bases on Single-Core and Dual-Core Processors

NxN	Piecewise Constant		
	ADSP BF-533 (sek.)	ADSP BF-561 (sek.)	Tezlashtirish koeffitsiyenti
16x16	0,023632	0,015521	1,52
32x32	0,381383	0,226987	1,68
64x64	6,225121	3,5409972	1,76
128x128	101,03015	56,30185548	1,79
256x256	1640,14715	895,1995021	1,83
512x512	26619,0109	14412,71198	1,85
1024x1024	434488,594	233485,9341	1,86

Conclusion

The results of the study demonstrate that parallel computation algorithms for two-dimensional geophysical signals based on Fast Haar transforms and bipolynomial bases provide significant efficiency gains. Parallel computations implemented on the ADSP-BF561 processor achieved acceleration factors ranging from 1.52 to 1.86 compared to a single-core processor. The difference in computation time becomes particularly notable for arrays of size 1024×1024. This confirms the advantages of parallel algorithms for real-time processing, remote geophysical surveys, and the analysis of large volumes of electromagnetic data. The proposed approach represents an important practical solution for enhancing the efficiency of geophysical analysis technologies.

References

1. Зайнидинов Х.Н. Методы и средства цифровой обработки сигналов в кусочно-полиномиальных базисах. // Монография, Академия государственного управления при Президенте РУз. Т: «Fan va texnologiyalar», 2014, -С. 192

2. Зайнидинов Х.Н., Зайнутдинова М.Б, Ибрагимов С.С. Алгоритм и программа цифровой обработки двумерных сигналов в биполиномиальных базисах. Кимёвий технология назорат ва бошқарув халқаро илмий-техника журнали 2017 й. 2-сон. 58-62 б.

3. Пономарев А.В. Основы теории двумерной цифровой обработки сигналов в базисах Фурье с варьируемыми параметрами. // Вестник ИжГТУ им. Калашникова М.Т. 2019. – Т. 31. – № 15. – С. 27-35.

4. Свиньин С.Ф. Базисные сплайны в теории отсчётов сигналов. -Спб.: Наука, 2003. – 118с

5. Ибрагимов С.С., Икки улчовли сигналларга ракамли ишлов беришда Хаар тез ўзгартириш алгоритми Toshkent amaliy fanlar universiteti “Innovatsion texnologiyalar: ilmiy g‘oyalar va ishlanmanalarni amaliyotga joriy etish masalalari va yechimlari” mavzusidagi xalqaro qoshma ilmiy-amaliy konferensiya Toshkent 2023 yil 26-27 may 10-12 b.

6. Пономарев А.В, Пономарева О.В. Роль и место операции дополнения нулями в теории двумерной Фурье-обработки сигналов // Цифровая обработка сигналов. 2020. №3. С. 50-55.
7. Сергеев В.В., Чичева М.А. Теория цифровой обработки сигналов и изображений: учеб. – Самара: Изд-во Самар, гос. аэрокосм, ун-та, 2013. – 216 с.: ил.
8. Takahashi D. Fast Fourier Transform Algorithms for Parallel Computers. Springer Nature Singapore Pte Ltd. 2019 – p.120.
9. Zaynidinov H.N., Ibragimov S.S., Tojiboyev G‘.O. Comparative Analysis of the Architecture of Dual-Core Blackfin Digital Signal Processors. International Conference On Information Science And Communications Technologies: Applications, Trends And Opportunities http://www.icisct2021.org/ ICISCT 2021, November 3-5, 2021. https://ieeexplore.ieee.org/document/9670135 (SCOPUS). p.1-5
10. Zaynidinov H.N., Ibragimov S.S., Tojiboyev G‘.O., Nurmurodov J.N. Efficiency of Parallelization of Xaar Fast Transform Algorithm in Dual-Core Digital Signal Processors. 2021 8th International Conference on Computer and Communication Engineering (ICCCE). 22-23 June 2021, Kuala Lumpur, Malaysia (SCOPUS). p. 7-12
11. Zaynidinov H.N., Ibragimov S.S., Yusupov I., Tojiboyev G‘.O. Algorithm and Program for Parallel Calculating of Xaar Fast Transform in Dual-Core Special Processors. Journal of Multidisciplinary Engineering Science and Technology. ISSN: 2458-9403 (Online) Vol. 7 Issue 9, September – 2020. p. 12696-12703.

Web of Technology: Multidimensional Research Journal
webofjournals.com/index.php/4