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USING DLP TO OPTIMIZE COMPUTER MODELS IN SCADA SYSTEMS

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Abstract. *This paper presents a study on the efficiency of applying data-level parallelism using SIMD technology to optimize computer models within SCADA systems. The focus is on implementing computational algorithms based on explicit and implicit finite difference schemes, which are widely used in industrial process modeling. Experimental research demonstrates improved computational performance achieved through the use of modern SIMD instructions, primarily AVX-256, enabling real-time data processing for complex simulation models in industrial control systems. It was found that explicit finite difference schemes exhibit better suitability for vectorization compared to implicit schemes implemented using the Thomas algorithm. The practical significance of the results lies in enhancing the efficiency of SCADA systems through the optimal utilization of modern CPU capabilities, offering tangible benefits for industrial enterprises adopting this technology.*

Keywords: *Industry 4.0, SCADA, SIMD, parallel computing, finite difference schemes, vectorization, AVX-256.*

Modern SCADA systems (Supervisory Control and Data Acquisition) are key components of the digital transformation in manufacturing, providing real-time data acquisition, analysis, and control of technological processes [1]. With the evolution of the Industry 4.0 paradigm and the integration of artificial intelligence elements into industrial systems, the need for high-performance computational algorithms has become critical. The requirement to process large volumes of data and perform complex computations in real time imposes stringent demands on the performance of algorithms used in these systems. Among such algorithms are computationally intensive tasks of numerical modeling, implemented through finite difference schemes for solving partial differential equations, particularly in problems related to heat transfer, hydrodynamics, and electromagnetism. Therefore, the development of efficient optimization algorithms, including the implementation of parallel computing [2, 3], for both types of schemes is a highly relevant issue.

DLP (Data-Level Parallelism) technology using SIMD (Single Instruction Multiple Data) provides a mechanism for performing the same operation on multiple data elements simultaneously [4-6]. Modern processors support advanced SIMD instruction sets such as AVX, AVX-256 (AVX2), and AVX-512 [7]. These allow simultaneous processing of 4, 8, 16, or more floating-point operands in single and double precision, respectively. However, the effective use of these technologies for finite difference schemes requires the development of specialized algorithms that take into account the specifics of computational patterns and data access structures [8].

As part of the study, a methodology was developed for optimizing numerical modeling algorithms in SCADA systems using SIMD. The software implementation was carried out in C++ with the use of the <immintrin.h> library, which provides access to SIMD instructions. As a result, scalar algorithms were implemented for both the explicit and implicit schemes, along with their vectorized counterparts utilizing double and float data types. In the implicit scheme algorithm, the solution of the SLAE (system of linear algebraic equations) was performed using the TDMA (Tridiagonal Matrix Algorithm).

Experimental verification of the developed algorithms was conducted using heat transfer models commonly employed in SCADA systems for monitoring and controlling industrial processes. The testing was performed on a modern Intel processor with support for AVX-256 SIMD instruction sets.

The experimental results demonstrate a speedup in computations when using optimized SIMD algorithms compared to traditional sequential implementations. The highest speedup (up to 1.89 times) is achieved for explicit schemes using single-precision floating-point data types with a high resolution of the computational grid ($>10^3$). Optimization of the implicit scheme algorithm shows a speedup of up to 1.41 times, which is a significant result considering the complexity of vectorizing it due to its sequential nature and the presence of recurrent dependencies. Overall, explicit finite difference schemes exhibit better suitability for vectorization compared to implicit schemes implemented using TDMA.

Conclusions. The conducted research confirms the potential of SIMD technology for optimizing algorithms in SCADA systems. The use of data-level parallelism allows improving the performance of solving problems with explicit and implicit finite difference schemes by approximately 1.4–1.9 times.

Promising directions for future research include the use of other SIMD instructions, particularly AVX-512, the development of hybrid algorithms that combine SIMD with other parallel computing technologies such as multithreading and GPU computing (CUDA), as well as adapting the developed methods to the specific requirements of various industries. Special attention will be given to optimizing machine learning algorithms, which are increasingly integrated into SCADA systems for process forecasting and optimization.

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ВИКОРИСТАННЯ DLP ДЛЯ ОПТИМІЗАЦІЇ КОМП'ЮТЕРНИХ МОДЕЛЕЙ У SCADA-СИСТЕМАХ

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Анотація. *В роботі представлено дослідження ефективності застосування технології паралелізму на рівні даних SIMD для оптимізації комп'ютерних моделей у SCADA-системах на прикладі реалізації обчислювальних алгоритмів за явними та неявними кінцево-різницевими схемами, які широко застосовуються в моделюванні промислових процесів. Експериментальні дослідження демонструють підвищення обчислювальної продуктивності завдяки використанню сучасних SIMD-інструкцій, передусім AVX-256, дозволяючи реалізувати обробку даних у реальному часі для складних симуляційних моделей в промислових системах керування. Встановлено, що явні кінцево-різницеві схеми демонструють кращу придатність до векторизації порівняно з неявними схемами, реалізованими з використанням методу прогонки. Практична значимість результатів полягає в підвищенні ефективності SCADA-систем через оптимальне використання можливостей сучасних процесорів, що надає переваги для промислових підприємств, які впроваджують цю технологію.*

Ключові слова: *Індустрія 4.0, SCADA, SIMD, паралельні обчислення, кінцево-різницеві схеми, векторизація, AVX-256.*

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