OS15-4

Simdroid-EC から見た電子機器の熱流体解析ソフトに必要な新機能
Advancements in Electronic Cooling Simulation with Simdroid-EC: A Multiscale, Multiphysics Approach

○正　段志偉[*1]，秦玉玲[*1]，正　辛平[*1]，正　趙希禄[*2]
Zhiwei DUAN[*1], Yuling QIN[*1], Ping XIN[*1] and Xilu ZHAO[*2]
[*1] IBE ジャパン株式会社　IBE Japan Co., Ltd.
[*2] 埼玉工業大学　Saitama Institute of Technology

Electronic cooling is a critical challenge in modern technology, driven by the miniaturization and increased power density of electronic components. This paper introduces Simdroid-EC, a specialized electronic cooling simulation software developed by Beijing Internet Based Engineering Co., Ltd. Based on computational fluid dynamics (CFD), Simdroid-EC integrates multiscale, multiphysics, and cross-domain capabilities to address complex thermal management problems in electronics. The software features a library of over 40 electronic component models, enabling rapid "building-block" modeling and high-quality hexahedral mesh generation (supporting up to billions of grid elements). Algorithmically, it employs unstructured Cartesian grids, finite volume discretization, and SIMPLE-like pressure-velocity coupling methods, combined with matrix-level conjugate heat transfer (CHT) equations for enhanced convergence efficiency and accuracy. Innovations include GPU parallel computing (H20 GPU acceleration up to 20 times) and AI-based reduced-order models (ROMs) for a 1,000 times speedup while maintaining precision. The software's visualization tools, such as contour plots, vector fields, and streamline analysis, facilitate optimized thermal design. Applications in semiconductor chips, telecommunications, and new energy systems demonstrate its effectiveness in reducing R&D cycles and costs. This work highlights Simdroid-EC as a transformative tool for high-precision, high-efficiency electronic cooling solutions.

Key Words : Electronic cooling, Simdroid EC, CHT, GPU, AI-ROMs

1. Introduction

The rapid advancement of electronics, from high-performance semiconductors to compact communication devices, has intensified the demand for efficient thermal management. Excessive heat dissipation in electronic systems can lead to performance degradation, reliability issues, and even catastrophic failures. Traditional cooling methods, such as forced air or passive heat sinks, often fall short in addressing the complexity of modern designs. Computational fluid dynamics (CFD) has emerged as a vital tool for simulating and optimizing thermal systems, but existing solutions face challenges in scalability, accuracy, and computational efficiency.

To address these limitations, Simdroid-EC is introduced as a cutting-edge electronic cooling simulation platform. This paper presents the architecture, algorithms, and applications of Simdroid-EC, emphasizing its innovations in multiscale modeling, GPU-accelerated computation, and AI-based reduced-order models (ROMs). The software's ability to handle complex geometries, coupled with its integration of advanced numerical methods and machine learning, positions it as a breakthrough in the field of electronic thermal management.

2. Related Work

CFD has been widely adopted for electronic cooling due to its ability to model fluid flow, heat transfer, and conjugate heat transfer (CHT) phenomenon[1]. Early studies focused on simplified geometries and steady-state assumptions. However, real-world electronic systems require transient, multiscale, and multiphysics simulations.

The computational intensity of CFD simulations has driven the adoption of GPU acceleration. NVIDIA's CUDA framework has enabled real-time simulations in aerospace and automotive industries[2]. However, GPU utilization in electronic cooling remains limited, particularly for large-scale, transient problems. Simdroid-EC leverages H20 GPU hardware to achieve a 20 times speedup in solving Navier-Stokes equations, as detailed in next section.

Recent advances in machine learning have introduced reduced-order models (ROMs) for accelerating simulations[3]. ROMs approximate high-fidelity CFD results using surrogate models trained on historical data. While promising, most ROMs sacrifice accuracy for speed. Simdroid-EC's AI-optimized ROMs maintain sub-1% error margins while achieving a 1,000 times acceleration, a significant improvement over conventional methods.

3. Results and Discussion

Simdroid-EC integrates a series of advanced GPU acceleration techniques aimed at maximizing computational efficiency and minimizing data transfer overhead in large-scale electronic cooling simulations. These optimizations span multiple levels, including memory management, execution concurrency, and multi-GPU scalability.

A key feature of Simdroid-EC is its native GPU-based solver, in which both data storage and numerical computations are performed entirely on the GPU. This design eliminates frequent data exchanges between the CPU and GPU that are common in heterogeneous computing environments, thereby reducing communication latency and fully leveraging the parallel computing power of the GPU. To further enhance performance, Simdroid-EC implements a multi-stream asynchronous execution model. In this model, GPU computations and CPU-side control logic are overlapped to avoid idle time. Moreover, multiple GPU computation streams are executed concurrently, ensuring high GPU utilization and efficient resource allocation.

The software also features optimized utilization of GPU memory hierarchies, including global memory, shared memory, and constant memory. By exploiting the distinct access patterns and performance characteristics of each memory type, Simdroid-EC achieves high memory bandwidth efficiency and reduced access latency. The data structures used in the native GPU solver for fluid field computation are specifically designed to approach theoretical optimal data access performance. Additionally, spatial locality in memory access is optimized to improve cache utilization.

Finally, Simdroid-EC supports efficient multi-GPU parallelization across different platforms: On Windows systems, it adopts the standard GPU‑CPU‑GPU data transfer path to enable multi-device computations. On Linux systems, it integrates high-performance communication libraries such as NCCL (NVIDIA Collective Communications Library) and CUDA-aware MPI, allowing efficient and scalable inter-GPU data exchange. These GPU acceleration techniques collectively enable Simdroid-EC to deliver high-performance, scalable solutions for complex electronic cooling applications. As shown in Figure 1 and 2.

Simdroid-EC integrates an advanced AI ROM/surrogate model to address the growing demand for faster and more accurate results prediction. Leveraging the Neural Network Universal Approximation Theorem, this feature enables rapid predictions while maintaining high accuracy. Figure 4 shows the analysis results by CHT and ROM, and their relative errors.

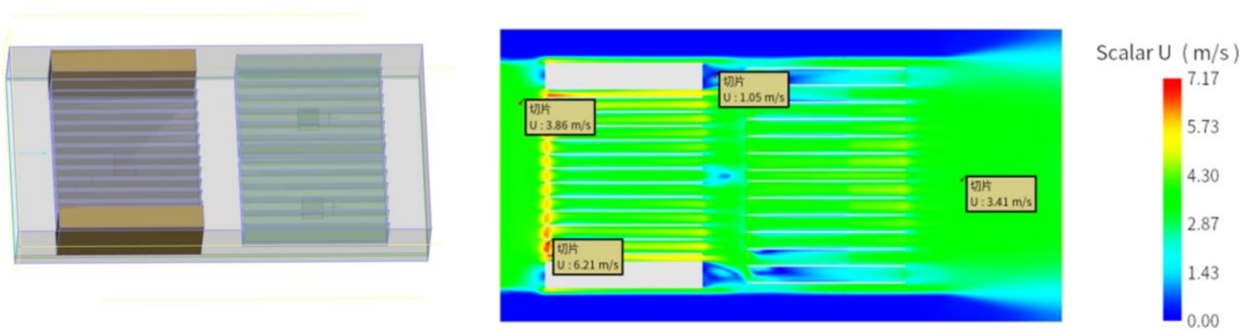


Figure 1　Forced Convection of a simplified Chassis

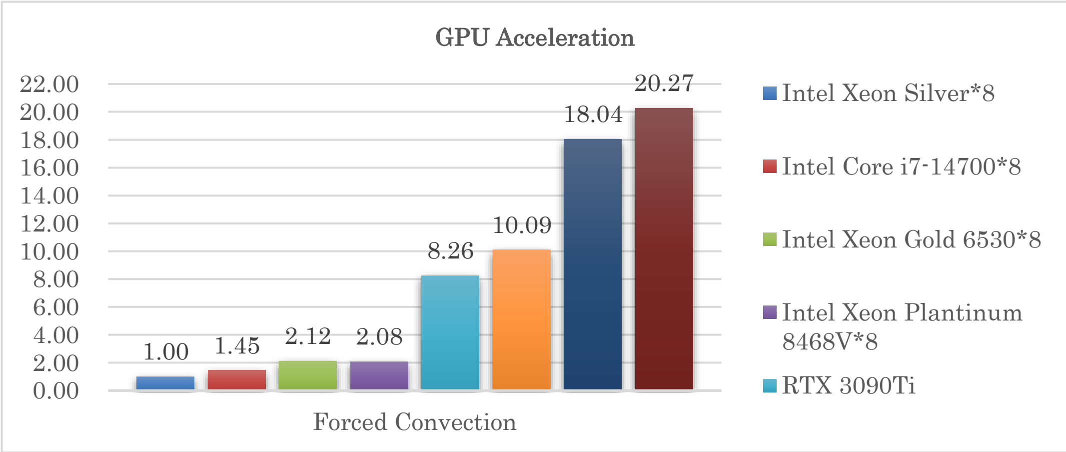


Figure 2　GPU Acceleration of Forced Convection Case

The AI surrogate model is structured as a plugin with multiple layers: the Training and Inference Layer handles model training and prediction generation; the Models Layer offers various pre-defined models for selection; and the Thirdparty Dependency Libraries ensure compatibility and flexibility by integrating essential external libraries. This modular design streamlines the modeling process from input data selection to final prediction.

Simdroid-EC's AI surrogate model achieves second-level prediction accuracy through several key features. It supports over ten types of algorithms, allowing users to choose the most suitable one for their specific needs. GPU acceleration further enhances computational efficiency, significantly reducing processing time. Multi-fidelity data fusion integrates data from various sources, ensuring robust and precise model training. Automatic hyperparameter optimization automates the tuning process, minimizing manual intervention and optimizing model parameters for the best outcomes.

This technology seamlessly integrates with solvers, applications (APPs), and optimization tools within Simdroid-EC, enabling comprehensive workflows from initial design to final optimization. By combining advanced AI techniques with powerful computational resources, Simdroid-EC empowers engineers and researchers to achieve faster, more accurate results, driving innovation and efficiency in engineering simulations.

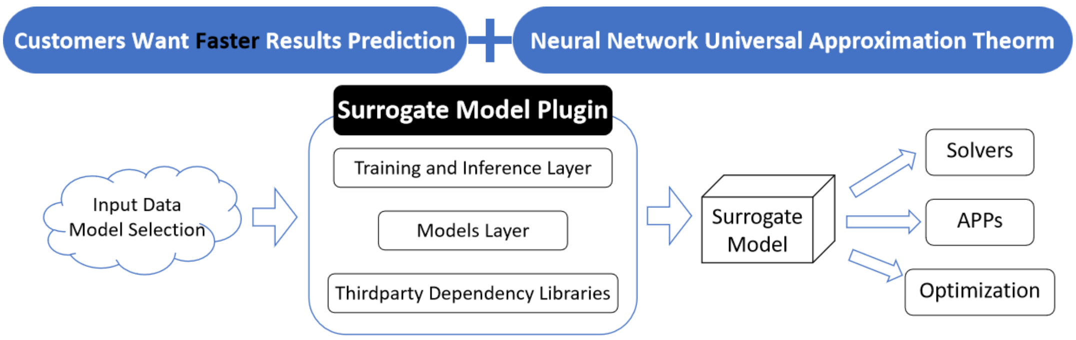
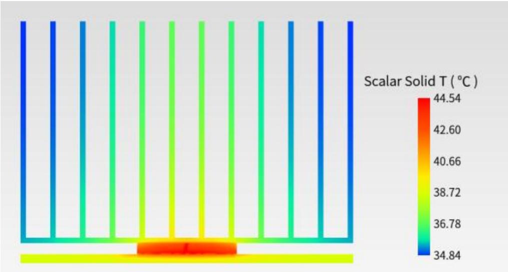
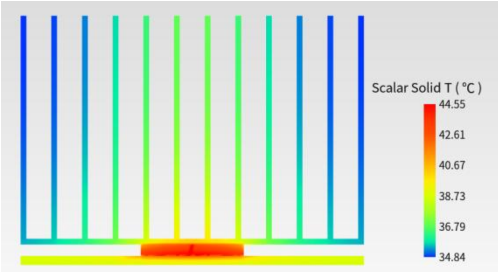


Figure 3　AI ROM/Surrogate model

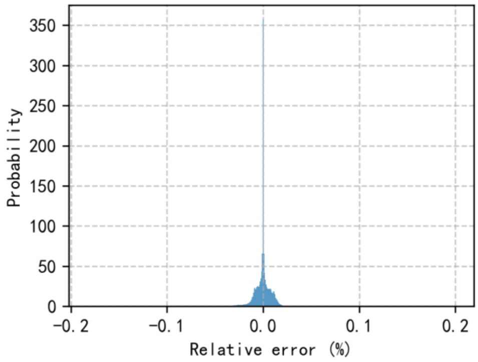
We utilize the surrogate model to enable fast and accurate thermal analysis in electronic cooling applications. Based on 24 training samples, with fin angle and length as key parameters, the model accurately predicts the temperature field across the system. The predicted results show excellent agreement with full-scale simulations, with a maximum relative error of only 1.1% and a mean relative error of 0.007%. The error distribution is tightly concentrated around zero, demonstrating the model's consistency and reliability. In addition to high accuracy, surrogate model provides more than 1000 times speedup in computation time, drastically reducing the cost of iterative design and optimization. By integrating AI-driven surrogate modeling, Simdroid-EC empowers engineers to rapidly explore design alternatives and achieve efficient thermal management solutions without compromising fidelity. This capability is especially valuable in early-stage product development where fast turnaround and high confidence in results are critical.



(a) CHT Result



(b) ROM result



(c) Relative error of simulation results by CHT and ROM

Figure 4 Analysis results by CHT and ROM, and their relative errors

4. Conclusion

Simdroid-EC represents a paradigm shift in electronic cooling simulation. Its integration of multiscale modeling, GPU acceleration, and AI-driven ROMs addresses the limitations of traditional CFD tools, enabling high-precision, high-efficiency thermal analysis. The software's applications in semiconductors, telecommunications, and new energy systems demonstrate its potential to transform R&D processes. Future work will focus on expanding the model library and enhancing AI-ROM adaptability for real-time decision-making.

References

(1) George, B.S., Aajan, M.P. "Steady-State and Transient Simulations of Heat Dissipation from an Electronic Component Kept in a Closed Enclosure Using OpenFOAM". In: Suryan, A., Doh, D., Yaga, M., Zhang, G. (eds) *Recent Asian Research on Thermal and Fluid Sciences.* Lecture Notes in Mechanical Engineering. Springer, Singapore. https://doi.org/10.1007/978-981-15-1892-8_39 (2020).

(2) NVIDIA blog, "Into the Omniverse: Computational Fluid Dynamics Simulation Finds Smoothest Flow With AI-Driven Digital Twins". https://blogs.nvidia.com/blog/computational-fluid-dynamics-digital-twins/

(3) Lige Zhao, Qi Zhou, Mengying Li, Zhe Wang, "Evaluating different CFD surrogate modelling approaches for fast and accurate indoor environment simulation", *Journal of Building Engineering*, Volume 95, 2024, 110221, ISSN 2352-7102, https://doi.org/10.1016/j.jobe.2024.110221.