Methods and apparatus for real-time simulation of nuclear fusion plasma based on a lightweight physics engine

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Research Field and Technical Objectives

The present invention discloses a method and apparatus for real-time simulation of nuclear fusion plasmas based on a lightweight physics engine, falling within the interdisciplinary field of computer graphics, GPU parallel computing and nuclear fusion engineering, and aims to address the core technical bottleneck in existing nuclear fusion plasma simulation technologies, which are unable to balance simulation accuracy with the real-time processing capabilities of standard mobile devices.

Core Technical Innovations and Implementation Schemes

Optimized Magnetohydrodynamic (MHD) Two-Fluid Model Construction

The present invention constructs a specifically simplified magnetohydrodynamic two-fluid model, precisely eliminating secondary physical equations that have no significant impact on the macroscopic motion of the plasma, whilst retaining the three core governing equations: the continuity equation, the momentum equation and the energy equation;

Customized CUDA Parallel Computing Architecture

It designs a CUDA parallel computing architecture tailored to the physical characteristics of the plasma; based on the Alvén time scale and CFL stability conditions, it sets a precise solution time step of 1×10^{-10} seconds, and combines the Particle Mesh (PM) algorithm to optimise long-range Coulomb interaction calculations;

Three-Level Adaptive Accuracy Control Mechanism

pioneered a three-level adaptive accuracy control mechanism featuring deep coupling between physical calculations and graphics, with different distance ranges corresponding to differentiated electromagnetic calculation logic and particle characterisation methods;

High-Precision Plasma Visualization Technology

established a dedicated plasma optical parameter database, generated continuous three-dimensional density fields via nuclear density estimation, and employed ray-stepped volume rendering combined with Laplace edge enhancement to achieve high-precision visualisation.

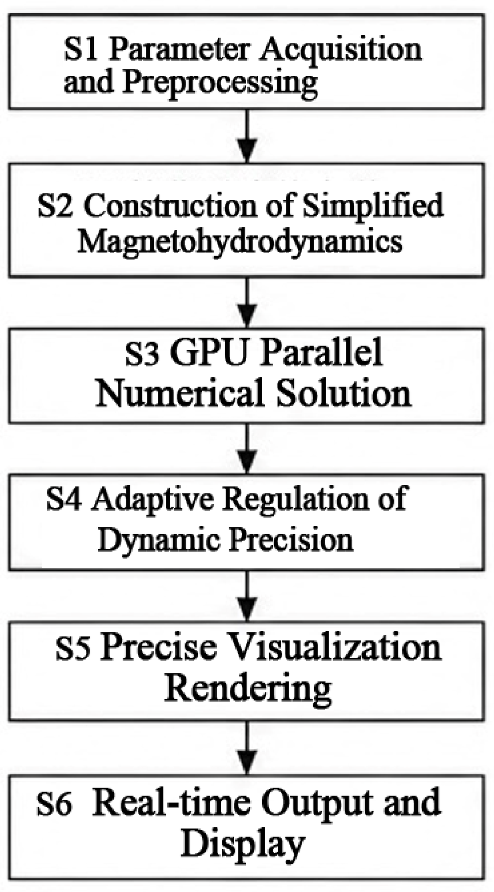

Fig. 1 Overall flowchart of the real-time simulation method for nuclear fusion plasma based on a lightweight physics engine.

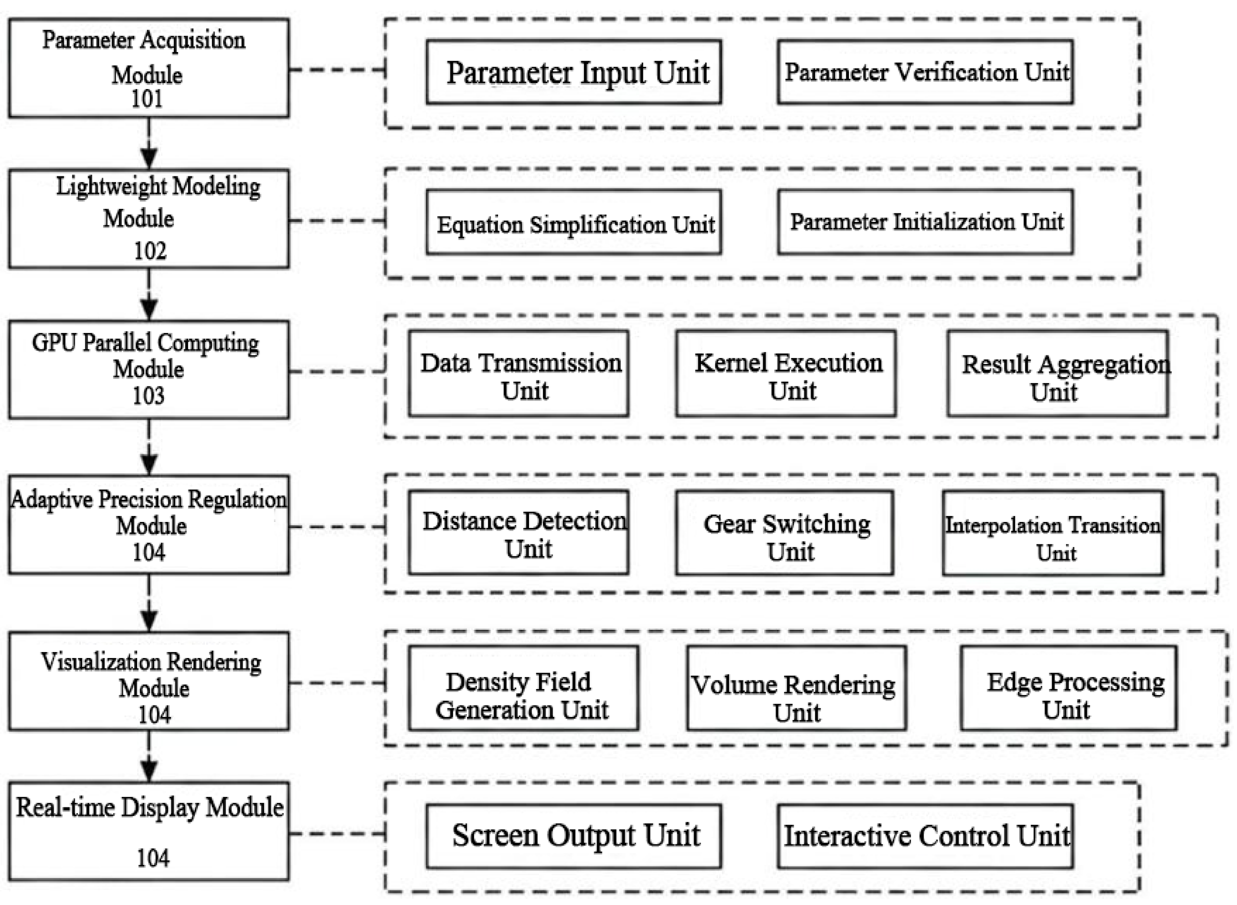

Fig. 2 Schematic diagram of the modular structure of the real-time simulation system for nuclear fusion plasma based on a lightweight physics engine.

Experimental Verification and Performance Indicators

◻ *Simulation Accuracy and Computational Efficiency*

Experimental validation confirms that, whilst ensuring the average error for the three core macroscopic parameters-plasma electron temperature, average particle density and circumferential velocity—remains below 8 per cent, the computational load is reduced by 87.5 per cent compared to a full MHD model.

◻ *Real-Time Rendering Performance on Different Platforms*

The system can stably achieve real-time rendering at 55 frames per second or higher on mobile devices with a Snapdragon 8 Gen 1 or higher processor real-time rendering on Snapdragon 8 Gen 1 and higher mobile devices, and over 65 frames per second on a desktop system with a Core i5-12400 processor.

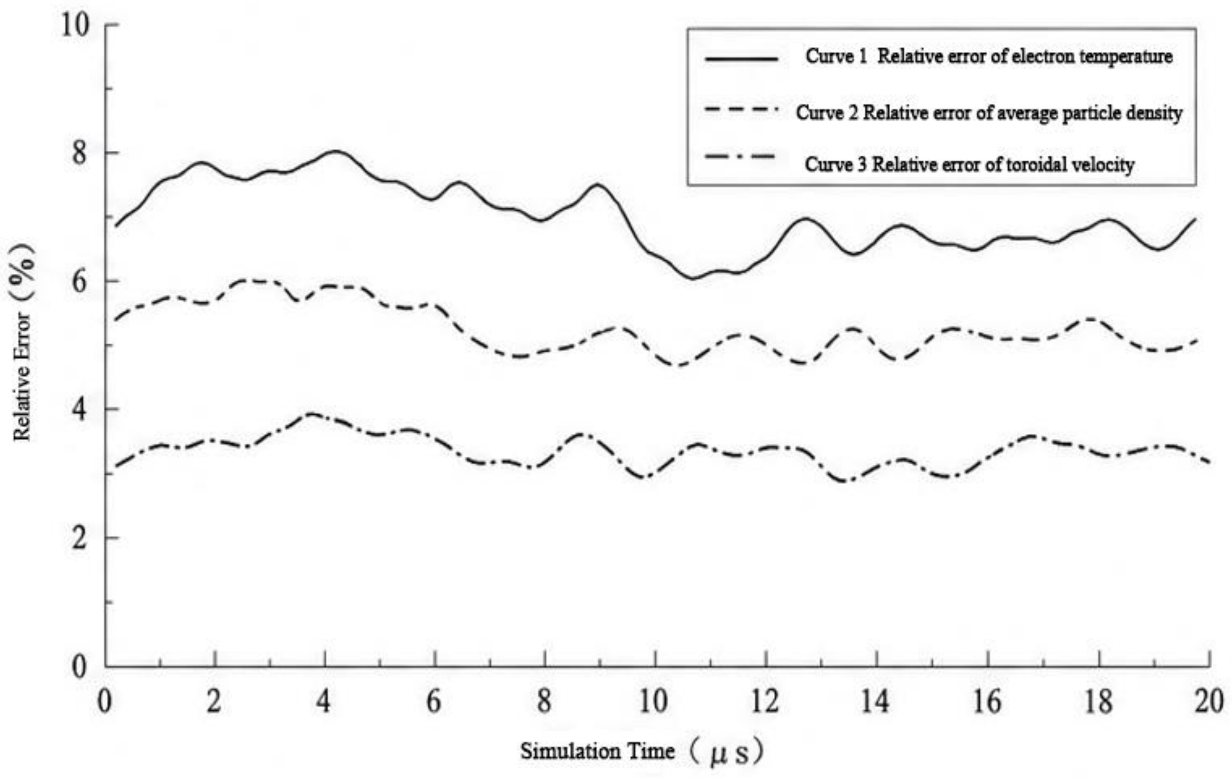

Fig. 3 Comparison graph of core parameter errors between the simplified model and the full MHD model in the embodiment.

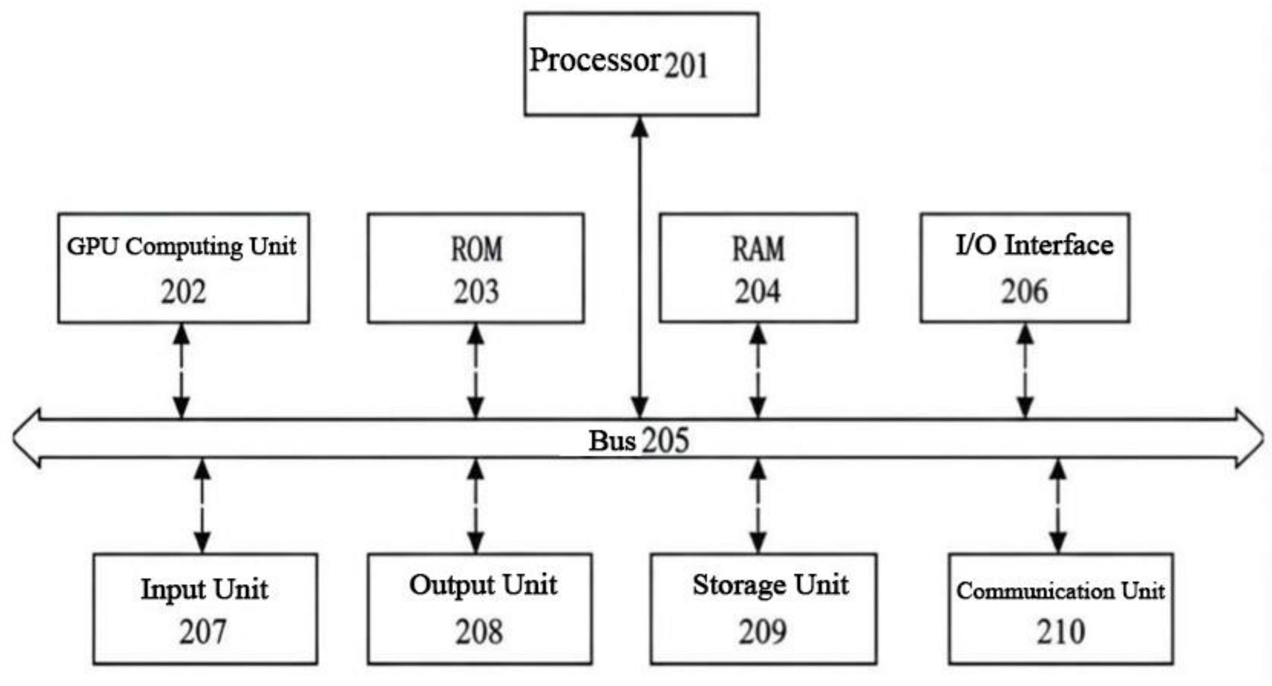

Fig. 4 Hardware block diagram of the electronic equipment used to implement the method of the present invention.

Application Scenarios and Practical Value

It is suitable for scenarios such as nuclear fusion science education, operational simulations of small-scale tokamak devices, and plasma physics teaching simulations, demonstrating outstanding technological innovation and practical value.

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