Patent Search

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Abstract:

ABSTRACT OF THE INVENTION The present invention relates to a method and device for mathematical modeling and optimization of complex dynamical and multi-ph systems by integrating state-of-the-art machine learning and artificial intelligence techniques with rigorous mathematical frameworks derived from recent scientific li invention addresses critical limitations in conventional computational tools, which treat physics-based modeling and data-driven AI as separate, disconnected pipelin in physically inadmissible predictions, poor uncertainty quantification, and inability to handle real-time multi-objective optimization under dynamic operating conditi of the invention is a layered, co-designed computational architecture comprising five principal components: (i) a Physics-Informed Neural Network (PINN) engine that governing ordinary and partial differential equations as composite loss terms using automatic differentiation and an adaptive augmented Lagrangian weighting sche Gaussian Process Regression (GPR) uncertainty quantification layer that provides calibrated Bayesian posterior predictive distributions over model outputs, enabling informed decision-making; (iii) a Transformer-based temporal attention module for processing high-frequency sequential sensor data with causal self-attention mech respect physical causality; (iv) a multi-objective Reinforcement Learning optimizer based on Proximal Policy Optimization with entropy regularization and Pareto-arch buffers for identifying Pareto-optimal design solutions under competing engineering objectives; and (v) a federated learning coordination layer supporting privacy-pr distributed model training across geographically separated data nodes using homomorphic encryption-based secure gradient aggregation with Byzantine fault tolera device embodiment of the invention incorporates a hardware accelerator unit (FPGA or GPU-based) implementing 8-bit quantized neural network inference with pipe dataflow architecture achieving latency below 10 milliseconds, a real-time drift detection engine using sliding-window statistical tests for automatic model retraining, explainability module generating SHAP-based feature attribution maps for physically interpretable model diagnostics. An online learning module with Kalman filter-b learning rate adaptation enables continuous model updating in non-stationary environments without catastrophic forgetting. The invention has been validated on m benchmark complex systems including the Lorenz chaotic attractor, IEEE 14-bus power network, and finite element structural models, demonstrating 38-65% improv prediction accuracy and 2.1x to 4.7x reduction in optimization convergence time over comparable state-of-the-art systems. Application domains encompass structura monitoring, electrical power grid optimization, chemical process control, biomedical signal analysis, and autonomous systems navigation. The modular API design en domain experts to specify custom physical constraint equations, objective functions, and learning schedules without requiring expertise in AI or embedded hardware programming, substantially lowering the barrier to deployment in real-world engineering environments.

Complete Specification

Description:c) Summary of the Invention
The present invention discloses a novel method and device for mathematical modeling and optimization of complex dynamical and multi-physics systems through a integrated AI/ML computational framework. The invention encompasses a layered architecture comprising: (i) a Physics-Informed Neural Network (PINN) engine tha enforces governing differential equations as hard or soft constraints within the network loss function; (ii) a Gaussian Process Regression (GPR) layer providing princi Bayesian uncertainty quantification over the surrogate model outputs; (iii) a Transformer-based temporal attention module that processes sequential sensor data a distills long-range dependencies critical to time-varying system identification; (iv) a multi-objective Reinforcement Learning (RL) optimizer that navigates the Pareto of competing design objectives using proximal policy optimization and entropy regularization; and (v) a federated learning coordination layer enabling distributed m training across geographically separated data nodes while preserving data locality and privacy.
The device instantiation of the invention incorporates a hardware accelerator unit (FPGA or GPU-based), a real-time data acquisition module with built-in calibratior routines, a model versioning and rollback engine with formal drift detection, and an explainability module that generates physically interpretable sensitivity maps th integrated gradients and SHAP-based attribution. Together, these components implement a closed-loop system identification and optimization pipeline capable of operating at inference latencies below 10 milliseconds for systems with up to 10,000 state variables.
, Claims:CLAIMS
1. A computer-implemented method for mathematical modeling and optimization of complex dynamical systems using an integrated machine learning and artificia intelligence framework, said method comprising: receiving, by a data acquisition module, real-time multivariate measurement data from a plurality of sensor nodes

View Application Status

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