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Hybrid physics-data driven model for real-time risk assessment of wind-induced disasters

摘要

针对典型灾害事故场景（火灾、极端大风天气等）实时、精细化风场模拟的迫切需求，提出了一种物理启发-数据驱动的两阶段深度学习方法框架，用于对具有高维输入不确定性的复杂风场进行快速重构。具体地，基于深度学习直接建立端到端预测模型，在网络架构设计、网络输入特征与输出量选取时充分考虑了流体物理机理以捕获 CFD 建模的显著特征，而数据驱动的误差修正技术可以填补实测数据和预测模型预测之间的剩余空白，捕获真实物理条件下存在的不确定因素。进一步地，提出了一种基于本体技术和知识库构建的事故智能推演仿真框架，具体地，基于公共安全三角形模型构建涉及承灾载体、突发事件、应急管理及后果的多层级安全信息本体模型；基于事件链、预案链理论构建耦合事故演化过程知识库，从而实现相应事故的仿真推演系统开发。以此为基础，结合风场重构研究成果，研发了用于行人、树木等承灾载体的物理-数据混合驱动实时风险评估系统。

关键词

深度学习；风场重构；风险评估；系统开发

Abstract

In response to the urgent demand for real-time, high-resolution wind field simulations in typical disaster scenarios, this study proposes a physics-inspired, data-driven two-stage deep learning framework for the rapid reconstruction of complex wind fields. Specifically, an end-to-end deep learning model is developed for direct prediction. The network architecture design, along with the selection of input features and output variables, explicitly incorporates fluid dynamics principles to capture the key characteristics of CFD modeling. Meanwhile, data-driven error correction techniques are employed to bridge the gap between measured data and model predictions, enabling the model to better account for uncertainties under real-world physical conditions. Furthermore, an intelligent accident simulation framework based on ontology technology and knowledge bases is proposed. A multi-level safety information ontology model is constructed, covering disaster-prone entities, emergency events, emergency management processes, and consequences, based on the public safety triangle model. In addition, a knowledge base for the coupled evolution of accidents is developed using event chain and contingency plan chain theories, thereby supporting the construction of a simulation and scenario-based system for accident analysis. Building upon this foundation, and integrating the results of is developed for disaster-affected entities such as pedestrians and trees.

Keywords

Deep learning; wind field reconstruction; risk assessment; system development

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