A High-Resolution Meshfree Method for Continuum Crowd Models with Applications to Evacuations During Flood Inundation and Smoke Propagation

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ABSTRACT

A profound understanding of the human motion dynamics in a large built environment during mass gatherings is essential in comprehending emergency evacuation interventions and safety-related protocols. Recent advancements in empirical observations of human psychological responses have revealed that the governing rules of human behavioral aspects can not only be predicted with adequate deterministic precision but also forged into mathematical formulations. These modeling studies enable crisis managers with reliable simulation tools to gain insights into critical facets of crowd disasters and enhance their decision-making abilities to facilitate safe egress in emergency situations.

However, an accurate description of intelligent living systems such as humans requires a rigorous mathematical modeling theory, which not only exhibits qualitatively consistent results but also replicates some of the inherent key features, such as self-organization, decision-making capability, and nonlinear interactions. The macroscopic scale of representation in this context is often invoked to comprehend large-scale collective human pattern formation in vast built environments, owing to its computational viability. The associated governing equations are typically constructed in a system of hyperbolic conservation law form, and the successful implementation of such models in real-world complex geometric configurations necessitates precise computational algorithms that are numerically stable, reasonably efficient, and robust. This work puts forward a high-resolution, shock-capturing meshfree particle method in an Eulerian framework for the numerical approximation of several widely adopted macroscopic pedestrian flow models. Then to study the collective behavior of crowds in a flooded evacuation scenario, we combine a macroscopic description of a crowd evacuation model with a hydrodynamic model of flood inundation described by a two-dimensional depth-averaged Shallow Water Equation (SWE), considering two-way dynamic coupling. Finally, a multi-group continuum crowd evacuation model is presented to simulate the emergent behavior of crowds from a smoke-impacted space.

Keywords Macroscopic pedestrian model; Crowd evacuation; Collective behavior; Traffic instability; Stop-and-go waves; Meshfree method; Geometric conservation; Flood evacuation; Coupled flood-crowd model; Multi-group continuum model; Smoke propagation; Behavioral dynamics in smoke