Open Access Crowd Simulations Using a Humanoid Paradigm.

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Abstract Dense crowds can pose real safety risks, yet existing crowd simulation paradigms struggle to capture the complex physical interactions at stake. Recent studies have highlighted the role of whole-body motion in high-density conditions. To integrate these findings into simulation, we propose to implement a new simulation paradigm involving humanoid-shaped agents in the open-source crowd simulation software JuPedSim [3], enabling more realistic crowd simulations.

Keywords Crowd Simulation, Humanoid shape, Whole body motion, Representation Paradigm.

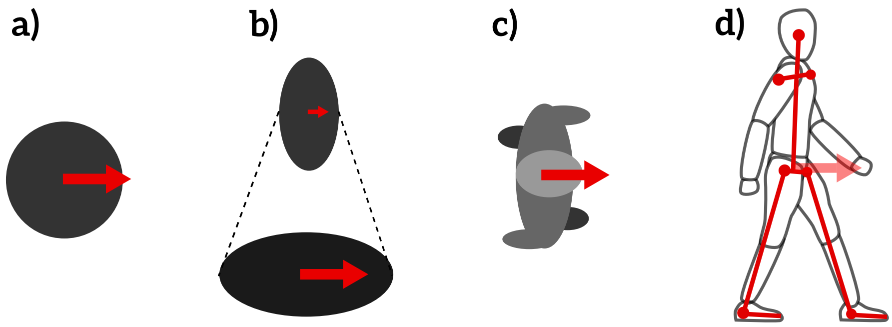

Figure 1: Overview of classical spacial representations of pedestrians for microscopic crowd simulations. a) Circular shape, used in first modelling approaches, up to modern simulations [11, 4]. b) Representation using shape-changing ellipsoids with variations as a function of pedestrian velocity [2]. c) Two-dimensional humanoid shape proposed in [10]. d) Simplified three-dimensional humanoid representation proposed in [8].

Introduction

Major events around the world have been shown to be prone to uncontrolled incidents, leading to discomfort, injury or even death [6]. One of the responses to such problems from the research community have been to create models and simulations in order to prevent such fate. So far, one of the most advocated purpose of crowd simulation is to be able to predict and prevent incidents in dense crowds [11]. However, crowd simulation seems to be mostly limited to the use of two main types of simulation paradigms.

The first type is a macroscopic simulation. In such simulations, the crowd is considered as a continuum medium, and only high-level quantities such as crowd density and flow volume are considered. These models are usually computationally efficient, but are based on continuum theory and struggle to capture complex mechanisms associated with physical interactions. Another classic paradigm for crowd simulation is microscopic simulation. In these, the simulated agents are independent entities driven by a set of rules. The overall crowd dynamics result from the interaction of the agents following the guidance of the rules to which they are bound. However, these models have been designed to handle light to medium densities where physical interactions do not occur. For dense crowds, this simulation paradigm is usually used with oversimplified, reciprocal and isotropic repulsion forces [4] or very limited balance recovery models [7].

In the meantime, recent experimental studies have attempted to provide a better picture of the mechanisms involved due to physical interaction in dense crowds [1, 9]. In particular, these mechanisms

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involve whole-body movement of pedestrians [5]. Even without physical interaction, high levels of density modify the gait cycle and involve advanced shoulder rotation [12].

In order to implement this new experimental knowledge, crowd simulations have to adapt to sub-microscopic representations of the human body that include different body parts. To this end, we decided to implement a novel representation paradigm for simulated agents in the open source software JuPedSim [3]. This new type of simulation is directly derived from the work of Shang et al. (2024) [8] who proposed a *Humanoid Model* for crowd simulation. The aim of this work is to provide the community with an accessible simulation framework that allows direct use of this new simulation paradigm through notebooks and direct comparison with experimental results.

References

[1] Thomas Chatagnon et al. "Standing balance recovery strategies of young adults in a densely populated environment following external perturbations". In: *Safety Science* 177 (2024), p. 106601. ISSN: 0925-7535. DOI: doi.org/10.1016/j.ssci.2024.106601.

[2] Mohcine Chraibi, Armin Seyfried, and Andreas Schadschneider. "Generalized centrifugal-force model for pedestrian dynamics". In: *Phys. Rev. E* 82 (4 Oct. 2010), p. 046111. DOI: 10.1103/PhysRevE.82.046111. URL: https://link.aps.org/doi/10.1103/PhysRevE.82.046111.

[3] Mohcine Chraibi et al. *JuPedSim*. Version v1.1.0. URL: https://github.com/PedestrianDynamics/jupedsim.

[4] E. Cristiani et al. "An all-densities pedestrian simulator based on a dynamic evaluation of the interpersonal distances". In: *Physica A: Statistical Mechanics and its Applications* 616 (2023), p. 128625. ISSN: 0378-4371. DOI: doi.org/10.1016/j.physa.2023.128625.

[5] Sina Feldmann et al. "Temporal segmentation of motion propagation in response to an external impulse". In: *Safety Science* 175 (2024), p. 106512. ISSN: 0925-7535. DOI: doi.org/10.1016/j.ssci.2024.106512.

[6] Claudio Feliciani et al. "Trends in crowd accidents based on an analysis of press reports". In: *Safety science* 164 (2023), p. 106174. DOI: 10.1016/j.ssci.2023.106174.

[7] Sujeong Kim et al. "Velocity-Based Modeling of Physical Interactions in Dense Crowds". In: *The Visual Computer* 31.5 (May 2015), pp. 541–555. ISSN: 1432-2315. DOI: 10/f696cv.

[8] Xiaoyun Shang et al. "Development and experimental validation of a humanoid pedestrian model that captures stepping behavior and body rotation". In: *Transportation Research Part C: Emerging Technologies* 158 (2024), p. 104446. ISSN: 0968-090X. DOI: doi.org/10.1016/j.trc.2023.104446.

[9] Liangchang Shen et al. "Experimental study on mechanical transfer regularity and step distance of individuals under different collision impulse". In: *Journal of Statistical Mechanics: Theory and Experiment* 2024.7 (July 2024), p. 073404. DOI: 10.1088/1742-5468/ad613c.

[10] Peter A. Thompson and Eric W. Marchant. "A computer model for the evacuation of large building populations". In: *Fire Safety Journal* 24.2 (1995), pp. 131–148. ISSN: 0379-7112. DOI: https://doi.org/10.1016/0379-7112(95)00019-P. URL: https://www.sciencedirect.com/science/article/pii/037971129500019P.

[11] Wouter van Toll et al. "SPH crowds: Agent-based crowd simulation up to extreme densities using fluid dynamics". In: *Computers & Graphics* 98 (2021), pp. 306–321. ISSN: 0097-8493. DOI: doi.org/10.1016/j.cag.2021.06.005.

[12] Jiayue Wang et al. "Step styles of pedestrians at different densities". In: *Journal of Statistical Mechanics: Theory and Experiment* 2018.2 (Feb. 2018), p. 023406. DOI: 10.1088/1742-5468/aaac57.