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**Crowd evacuation with human-level intelligence via neuro-symbolic approach**
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**Abstract**
Understanding human response to crowd emergencies is extremely complex, and it plays a significant role in engineering construction designs and crowd safety. Individual choices, reasoning, and behaviours cannot be fully described by equations or rule-based methods. Accordingly, this research proposes a neuro-symbolic approach for modelling agents with human-level capabilities of reasoning and performance in an emergency evacuation. The proposed neuro-symbolic approach combines deep reinforcement learning with evaluative fuzzy logic to address the challenges of large amounts of required data, time, and trials-and-errors for policy optimization and to handle the assumption of reward function that may not be practical in real scenarios. This neuro-symbolic model has the potential to deal with the complexity of the environment and decision-making process via deep reinforcement learning and enhances the cognitive and visual intelligence via an evaluative fuzzy function, which continuously evaluates agent actions during the training process to boost pedestrian active response to their surroundings, with full awareness of time, thereby, the human-level capacity of reasoning. Moreover, this proposed model optimizes the computational demands of deep reinforcement learning and enables faster learning of new situations. The findings indicate that the proposed model can produce behavioural patterns that align with real observations of crowd evacuation, such as laminar flow, stop-and-go flow, and crowd turbulence. On top of that, a new evacuation behaviour is observed, as some pedestrians avoid congestion at the exit until the density reduces which reflects a level of human reasoning. The proposed model illustrates a higher accuracy and much faster converge than the pure proximal policy optimization model with substantially minimal training timesteps of as little percentage as 2 to 8. Meanwhile, the reliability study records an increase of the mean and standard deviation of evacuation time from 39.7 s, 1.06 to 155.09 s, 7.39 as crowd size increases from 15 to 200 pedestrians, which implies a rise of uncertainty. Therefore, we perceive that this work can provide crowd authorities and construction engineers with insights into complex behaviour and critical conditions to make better evacuation plans and sustainable designs to ensure crowd safety. It also provides a promising alternative to the evident lack of data on critical crowd conditions. 

**Author Keywords**
Crowd evacuation; Decision intelligence; Deep reinforcement learning; Fuzzy logic; Neuro-symbolic approach

**Index Keywords**
Behavioral research, Computer circuits, Deep learning, Fuzzy inference, Laminar flow, Reinforcement learning, Safety engineering, Sustainable development; Crowd evacuation, Decision intelligence, Deep reinforcement learning, Fuzzy-Logic, Human level intelligence, Human levels, Human response, Neuro-symbolic approach, Policy optimization, Reinforcement learnings; Decision making

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