

A Crowd Pressure Index (CPI) Framework for Early Detection of Crush Hazards in High-Density Crowds

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Abstract— Crowd crush disasters occur when physical pressure within a densely packed crowd exceeds the threshold of voluntary human movement, resulting in sudden instability, asphyxiation, and large-scale casualties. Despite advances in urban surveillance, existing monitoring systems rarely provide quantitative indicators capable of detecting early signs of dangerous compression. This study proposes a real-time framework for assessing crowd crush risk using CCTV imagery, integrating P2PNet-based density estimation, interpersonal spacing analysis, and a newly formulated Crowd Pressure Index (CPI). The density D is computed from detected individuals per unit area, while spacing S is derived from nearest-neighbor distances, enabling CPI to capture both macroscopic congestion and microscopic compression dynamics. The model was evaluated using real-world footage from the 2021 Meron disaster and the 2022 Seoul Halloween crowd crush. Results show that when density exceeds 5–6 persons/m², physical contact becomes unavoidable, and at densities above 8–10 persons/m², spacing drops below 0.1–0.15 m, leading to rapid escalation toward collapse-prone states. CPI values exhibited a sharp increase in the final seconds before both disasters, demonstrating the index’s sensitivity to pre-collapse signatures. The prototype achieved real-time performance, maintaining an average processing latency below 2 seconds. These findings indicate that the proposed CPI-based framework provides a quantitative and practical foundation for proactive crowd-safety management. The method can support early-warning systems for large-scale events, transportation hubs, and urban gatherings. Future research will extend the model toward predictive pressure-wave forecasting and multimodal sensor integration to enhance generalizability in diverse environments.

Keyword—Crowd Density Estimation, Crowd Crush Prediction, Crowd Pressure Index (CPI), Interpersonal Spacing, P2PNet, YOLOv8, DBSCAN, Computer Vision, Deep Learning, CCTV Analytics, Real-Time Surveillance, Crowd Safety Management, High-Density Crowd Dynamics



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