Multi-Source Data Integration for Urban Disaster Estimation and Assessment Based on Remote Sensing and Social Sensing

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Abstract

Urban flood disasters pose increasing risks to human life, infrastructure, and socio-economic systems, particularly in densely populated cities where physical hazard processes and human behavioral responses interact in complex ways. From a theoretical perspective, this dissertation adopts a knowledge-oriented integration perspective that emphasizes the combined use of physical sensing data and human behavioral information for urban flood extent estimation. This perspective is grounded in Knowledge Science, emphasizing the transformation of diverse data sources into interpretable and actionable knowledge for disaster management.

To operationalize this concept, this dissertation proposes a comprehensive multi-source data integration framework that combines remote sensing, geographic information, and social sensing for urban flood estimation and assessment. The framework is applied to the 2019 Typhoon Hagibis flood in Nagano City, Japan, serving as a representative case of an urban riverine disaster.

The research is structured around three incremental experiments. Experiment I examines temporal and spatial anomalies in large-scale mobile phone GPS data, demonstrating that population mobility patterns reflect flood-related disruption and public response. Experiment II develops Random Forest–based flood estimation models that integrate Synthetic Aperture Radar (SAR), Digital Elevation Model (DEM), terrain indices (TWI, SPI), and GPS-derived population density, showing that the inclusion of behavioral information improves spatial coherence and reduces misclassification. Experiment III advances the framework to a fine-gridded (70 m × 70 m) urban model by incorporating Twitter-derived information, enabling near–real-time situational awareness through the integration of physical indicators and human-reported flood impacts.

Across all experiments, the results confirm that multi-source data fusion enhances the timeliness, spatial precision, and interpretability of urban flood estimation. Physical sensing data provides stable representations of inundation and terrain conditions, while social sensing data capture dynamic population displacement and disaster perception, which together reduce false positives and improve the spatial coherence of flood extent estimation across all experiments. Their integration establishes a data-driven foundation for resilient city assessment. This dissertation contributes a unified methodological workflow linking sensing, data fusion, and application stages, demonstrating how theory-guided multi-source integration can support both real-time disaster response and long-term urban resilience planning.

Keywords:

Remote sensing; Social sensing; multi-source data integration; Urban flood estimation; Random Forest; SAR; GPS mobility data; Twitter data; Machine learning; Urban resilience; Disaster assessment