人工智慧雷達降水技術於豪雨即時監測與預警之應用

Application of Artificial Intelligence Radar Precipitation Technologies in Heavy Rainfall Real-Time Monitoring and Warning

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摘　要

隨著人工智慧(AI)與高效能運算電腦的快速發展，為兼顧作業時效與節能效益，並突破傳統降雨推估的物理限制，本研究整合AI技術與雙偏極化雷達資料，研發雷達定量降水估計(AI-QPE)與極短期定量降水預報(AI-QPF)技術。在AI-QPE方面，本研究導入極限梯度提升(XGBoost)與卷積神經網路(CFAD-CNN)兩種演算法。驗證結果顯示，XGBoost於降雨推估作業中展現較佳的誤差控制能力與時空分布一致性。雖然對強降雨仍有低估情形，但效能已優於傳統雷達QPE技術，均方根誤差由25.2降低至2.4毫米，改善幅度約90%。在AI-QPF方面，本研究成功開發軌跡閘道循環單元生成對抗網路(TrajGAN)與雷達深度生成(DGMR)模型。在產製未來6小時、10分鐘時間解析度的雨量預警產品時，模型推論僅需40秒即可完成，大幅提升運算效率。成效評估顯示，AI-QPF於中低強度降雨之臨界成功指數(CSI)、海德克技能得分(HSS)及命中率(POD)皆優於現行作業模組。然而，對強對流結構特徵之預報仍存在回波結構衰減過快的問題，後續仍需持續優化。上述研發成果皆已完成自動化作業模組建置，每10分鐘可產製即時降雨估計與0–6小時雨量預警產品，並於天氣與氣候監測網(WATCH)對外提供即時防災情資服務。

關鍵字：人工智慧、定量降雨估計、極短期定量降水預報、天氣與氣候監測網

Abstract

With the rapid development of artificial intelligence (AI) and high-performance computing, integrating AI technology with dual-polarization radar data has become essential to balance operational efficiency with energy savings, while breaking through the physical limitations of traditional rainfall estimation. This study develops advanced techniques for radar quantitative precipitation estimation (AI-QPE) and quantitative precipitation forecasting (AI-QPF). For AI-QPE, two machine learning algorithms—extreme gradient boosting (XGBoost) and convolutional neural networks based on contoured frequency by altitude diagrams (CFAD-CNN)—are introduced. Validation results indicate that XGBoost demonstrates superior error control and spatiotemporal consistency in precipitation estimation. Although it still tends to underestimate heavy rainfall, its performance outperforms traditional radar QPE techniques, reducing the root mean square error from 25.2 to 2.4 millimeters, which represents an improvement of approximately 90%. For AI-QPF, this study successfully develops the trajectory gated recurrent unit generative adversarial network (TrajGAN) and the deep generative model of radar (DGMR). To generate precipitation forecast products for the next 6 hours at a 10-minute temporal resolution, the model inference requires only 40 seconds, significantly enhancing computational efficiency. Performance evaluations show that for low-to-moderate intensity rainfall, the AI-QPF model outperforms current operational modules in terms of the critical success index (CSI), Heidke skill score (HSS), and probability of detection (POD). However, a rapid decay in echo structures remains a

challenge when forecasting strong convective features, necessitating ongoing optimization. All the aforementioned research and development achievements have been integrated into automated operational modules. These modules generate real-time precipitation estimations and 0–6-hour rainfall forecasts every 10 minutes, providing real-time disaster prevention information services through the weather analysis and Taiwan climate hybrid monitor system (WATCH).

Keywords: artificial intelligence (AI), quantitative precipitation estimation (QPE), quantitative precipitation forecasting (QPF), weather analysis and Taiwan climate hybrid monitor system (WATCH)