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MASTER THESIS

Artificial Intelligence for Early Forest Fire Detection and Smart Afforestation

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Summary

This thesis presents an intelligent system for early forest fire detection and smart afforestation in Algerian ecosystems using two complementary deep learning pipelines. Approach 1 combines a fine-tuned ResNet50 classifier with YOLOv11s, achieving 99.55% classification accuracy, a mAP@0.5 of 44.22%, and 10.3 FPS. Approach 2 adopts a unified YOLOv11 architecture for both classification and detection, achieving 99.38% accuracy, a higher mAP@0.5 of 76.86%, and 21.1 FPS, making it the most suitable solution for real-time deployment. Both approaches integrate a confidence-based fire intensity module with three severity levels (Strong, Medium, and Weak) and a smart afforestation recommendation engine based on the hybrid MAX+MEAN decision rule. The complete system is deployed as an interactive Streamlit dashboard for fire monitoring and post-fire ecological restoration.

Keywords: Deep Learning, YOLOv11, ResNet50, Forest Fire Detection, Smart Afforestation, Real-Time Monitoring, Algeria.

Résumé

Ce mémoire présente un système intelligent de détection précoce des incendies de forêt et de reboisement intelligent dans les écosystèmes algériens à travers deux pipelines d'apprentissage profond complémentaires. L'Approche 1 combine un classificateur ResNet50 fine-tuné avec YOLOv11s, atteignant une précision de 99,55 %, un mAP@0.5 de 44,22 % et une vitesse de 10,3 FPS. L'Approche 2 repose sur une architecture YOLOv11 unifiée assurant simultanément la classification et la détection, avec une précision de 99,38 %, un mAP@0.5 plus élevé de 76,86 % et une vitesse de 21,1 FPS, ce qui en fait la solution la plus adaptée au temps réel. Les deux approches intègrent un module d'évaluation de l'intensité des incendies basé sur la confiance ainsi qu'un moteur intelligent de recommandation pour le reboisement fondé sur la règle hybride MAX+MEAN. Le système est déployé sous forme d'un tableau de bord interactif Streamlit destiné à la surveillance des incendies et à la restauration écologique post-incendie.

Mots-clés : Apprentissage profond, YOLOv11, ResNet50, Détection des incendies de forêt, Reboisement intelligent, Temps réel, Algérie.

ملخص

يقدم هذا العمل نظاماً ذكياً للكشف المبكر عن حرائق الغابات وإعادة التشجير الذكي في النظم البيئية الجزائرية باستخدام نهجين متكاملين قائمين على التعلم العميق. يجمع النهج الأول بين مصنف ResNet50 المعدّل ونموذج YOLOv11s، محققاً دقة تصنيف بلغت 99.55%، وقيمة mAP@0.5 بلغت 44.22%، وسرعة معالجة قدرها 10.3 إطارًا في الثانية.

أما النهج الثاني فيعتمد على بنية موحدة قائمة على YOLOv11 لتنفيذ التصنيف والكشف معًا، محققًا دقة تصنيف بلغت 99.38%، وقيمة mAP@0.5 أعلى بلغت 76.86%، وسرعة 21.1 إطارًا في الثانية، مما يجعله الأنسب للتطبيقات الآنية. يدمج النظام وحدة لتقييم شدة الحريق وفق مستويات متعددة، إضافة إلى محرك ذكي لتوصيات إعادة التشجير يعتمد على قاعدة القرار الهجينة MAX+MEAN. وقد تم نشر النظام في شكل لوحة تحكم تفاعلية باستخدام Streamlit لدعم مراقبة الحرائق واستعادة النظم البيئية المتضررة.

الكلمات المفتاحية: التعلم العميق، ResNet50، YOLOv11، كشف حرائق الغابات، إعادة التشجير الذكي، المراقبة الآنية، الجزائر.