PROJECT REPORT

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INFOSYS SPRINGBOARD INTERN

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AI-Driven Archaeological Site Analysis System

1. Abstract

Limitations in traditional archaeological prospecting—specifically regarding scalability and terrain accessibility—necessitate the adoption of automated computational solutions. This project details the development of an AI-based system that integrates U-Net architectures for semantic land-cover segmentation and YOLO object detection models to identify potential archaeological structures within high-resolution aerial imagery. Furthermore, the system implements machine learning algorithms to forecast terrain erosion risks. By combining these distinct computational modules into a comprehensive interactive application, the project delivers a high-performance tool for automated large-scale spatial analysis, modernizing the approach to site identification and preservation.

2. Introduction

While archaeology plays a crucial role in understanding our past, traditional surveying methods are facing a bottleneck. The reliance on manual field surveys and human interpretation of imagery creates significant limitations regarding scalability, cost, and terrain accessibility. To overcome these challenges, the field is increasingly turning to computational solutions.

Recent breakthroughs in Artificial Intelligence enable the automated processing of high-resolution remote sensing data. By applying machine learning and deep learning techniques to satellite and aerial imagery, archaeologists can now identify potential sites and predict erosion risks with greater efficiency and precision.

This report details the design and implementation of an AI-driven system capable of analyzing archaeological landscapes. Through the application of advanced segmentation and detection algorithms, this project provides a scalable tool to accelerate site identification and enhance the preservation of historical assets.

3. Problem Statement

Current methodologies for identifying archaeological sites from aerial imagery rely heavily on manual visual interpretation. This process is inherently inefficient, labor-intensive, and highly susceptible to inter-observer variability and human error. As the availability of high-resolution remote sensing data increases, manual analysis becomes unscalable, often failing to detect subtle structural anomalies or adequately assess environmental threats such as soil erosion. Furthermore, existing workflows lack a consolidated framework to process these disparate data types simultaneously. Consequently, there is a critical need for a unified, automated system capable of performing scalable image analysis, precise structural detection, land-cover classification, and terrain stability evaluation to support effective site preservation.

4. Project Objectives

The primary objective of this project is to design and implement an integrated AI-driven framework for the automated identification, classification, and preservation assessment of archaeological sites. The specific technical objectives are as follows:

- Automated Semantic Segmentation: To develop deep learning algorithms capable of segmenting high-resolution aerial imagery into distinct semantic categories, accurately differentiating between vegetation, structural ruins, and background terrain.
- Object Detection Implementation: To deploy YOLO-based object detection models to precisely localize and identify discrete archaeological structures within complex spatial datasets.
- Erosion Risk Assessment: To construct and train machine learning models that analyze terrain features to predict erosion risks and assess environmental stability.
- System Integration: To consolidate the segmentation, detection, and predictive modeling components into a unified, interactive software application for seamless user interaction.
- Enhanced Visualization: To generate intuitive visual outputs and analytical overlays that facilitate the efficient interpretation of spatial data for archaeological research and decision-making.

5. Literature Motivation and Background

Contemporary research has established the efficacy of deep learning architectures in the domain of remote sensing and geospatial analysis. Specifically, the U-Net architecture has emerged as a standard for semantic segmentation due to its precision in pixel-level classification, while the You Only Look Once (YOLO) algorithm is widely recognized for its computational efficiency and accuracy in real-time object detection. Parallel to these developments in computer vision, ensemble machine learning algorithms notably Random Forest and XGBoost—have proven robust in environmental modeling and terrain risk assessment.

Building upon this body of work, this project synthesizes these distinct AI methodologies into a cohesive analytical framework. By integrating computer vision techniques for structural identification with machine learning models for environmental evaluation, this research aims to bridge the gap between visual archaeological interpretation and predictive terrain stability analysis.

6. Proposed System

The proposed system is designed as a modular AI-driven framework comprising three core analytical components, each specialized for distinct aspects of archaeological spatial analysis:

1. Semantic Segmentation Module: Executes pixel-level classification to accurately delineate and map diverse land-cover features.
2. Object Detection Module: Utilizes bounding-box regression techniques to localize and identify specific archaeological structures within the imagery.
3. Terrain Erosion Prediction Module: Analyzes topographical data to evaluate terrain stability and classify areas based on susceptibility to erosion.

These functional modules are orchestrated within a unified processing pipeline and deployed via an interactive dashboard, facilitating real-time data analysis and comprehensive visualization for end-users.

7. Methodology

The development of the proposed system adheres to a structured analytical pipeline, encompassing data engineering, model development, and system deployment. The methodology is divided into the following key phases:

- Data Acquisition and Preprocessing: Compilation of raw aerial imagery followed by normalization, augmentation, and annotation to create robust training datasets for subsequent modeling.
- Semantic Segmentation (U-Net): Implementation of the U-Net convolutional neural network architecture to perform dense prediction, classifying pixels into meaningful semantic categories such as vegetation, ruins, and background.
- Object Detection (YOLO): Deployment of a pre-trained YOLO (You Only Look Once) model, fine-tuned on archaeological datasets to enable the real-time localization and bounding-box detection of structural features.
- Feature Extraction & Terrain Analysis: Utilization of digital image processing techniques to extract topological features, which serve as inputs for environmental stability assessment.
- Erosion Prediction Modeling: Training and validation of supervised machine learning classifiers to predict erosion risks based on extracted terrain attributes.
- System Integration & Interface Design: integration of all distinct computational modules into a web-based interface, enabling interactive visualization and accessible user engagement.

8. System Architecture and Workflow

The system operates via a streamlined pipeline beginning with image preprocessing. The workflow subsequently branches into parallel execution paths: U-Net for semantic segmentation, YOLO for structural detection, and feature extraction for ML-based erosion prediction. These concurrent analytical outputs are finally consolidated and rendered within an interactive dashboard for unified visualization.

9. Implementation Details

The system implementation is built upon the following technical components:

- Semantic Segmentation: Implemented using a U-Net architecture integrated with a ResNet-based encoder for robust feature extraction.
- Object Detection: Utilizes the YOLO (You Only Look Once) algorithm to ensure efficient and accurate detection of archaeological structures.
- Terrain Analysis: Extracts critical environmental features, specifically vegetation ratios and slope scores, using OpenCV-based image processing techniques.
- Erosion Prediction: Employs a supervised machine learning model trained to classify terrain stability and predict erosion risks based on derived features.

- Deployment: The full analytical pipeline is integrated and deployed using the Streamlit framework to provide a responsive, interactive user interface.

10. Performance Evaluation

The system's performance was rigorously evaluated across its three core analytical components. The semantic segmentation model achieved precise pixel-level classification, effectively distinguishing between vegetation, structural ruins, and background topography. Concurrently, the YOLO architecture demonstrated high accuracy in the localization and bounding-box regression of archaeological structures. Furthermore, the erosion prediction module exhibited robust predictive reliability, validating the efficacy of the extracted terrain features for environmental risk assessment.

11. Results and Discussion

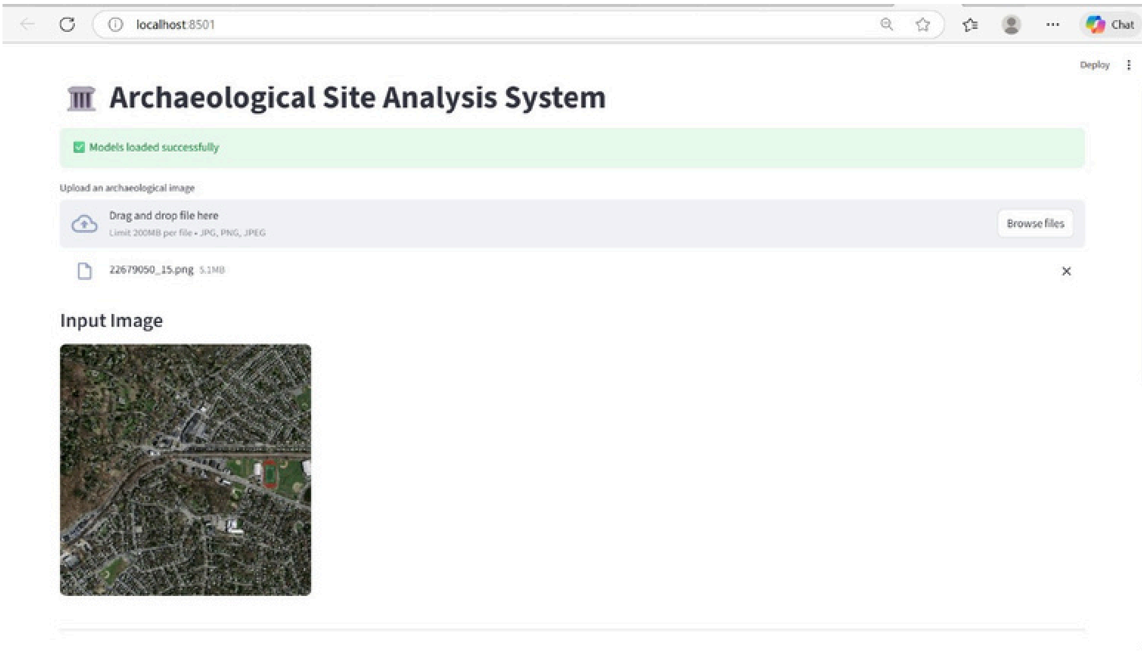
Experimental validation confirms that the integrated system effectively analyzes aerial imagery to derive actionable insights for archaeological assessment. By synthesizing pixel-level semantic segmentation, object-level structural detection, and feature-based terrain prediction, the proposed framework provides a comprehensive, multi-layered interpretation of archaeological landscapes. The results demonstrate that automating these distinct analytical tasks significantly enhances the speed and granularity of site evaluation compared to traditional methods.

12. Visualization and Dashboard

The system incorporates a Streamlit-powered interface designed to visualize the following analytical components:

- Raw aerial photography
- Semantic land-cover masks
- Structural detection bounding boxes
- Terrain stability indicators

This centralized display optimizes the user experience by providing immediate, graphical insights into the processed data.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Chat
Deploy
Archaeological Site Analysis System
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Limit 200MB per file • JPG, PNG, JPEG
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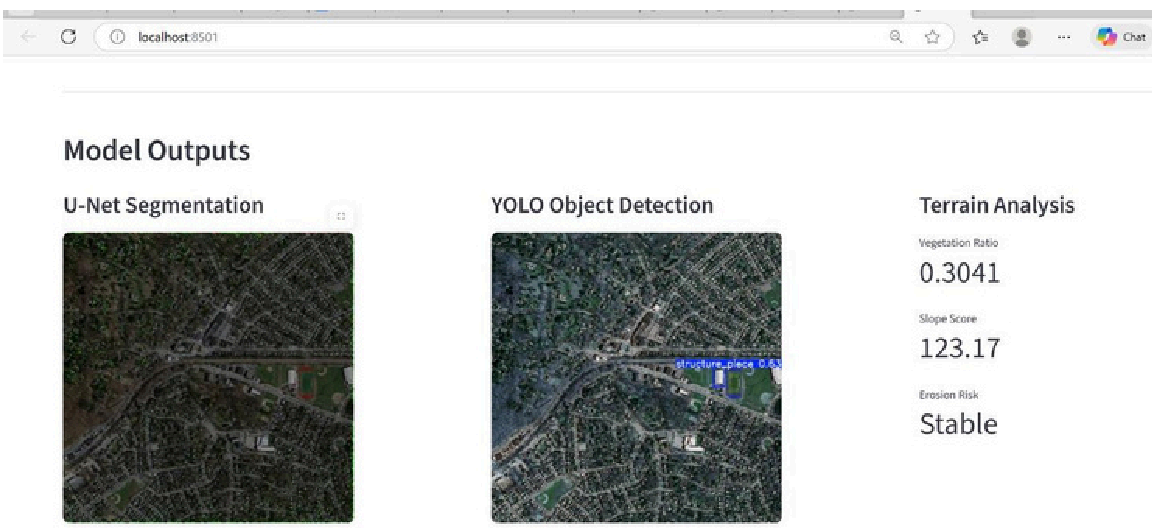
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Terrain Analysis
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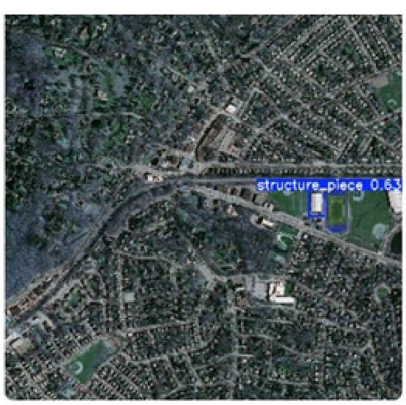
structure_piece

13. Conclusion

This project validates the integration of Artificial Intelligence, Machine Learning, and Computer Vision as a robust approach for automated archaeological analysis. By synergizing semantic segmentation, object detection, and erosion prediction, the system effectively reduces manual workload and optimizes analytical precision. Ultimately, this framework presents a scalable, efficient solution for advancing archaeological research and heritage preservation planning.

14. Future Work

Future iterations of the system will focus on expanding its analytical capabilities and scalability through the following enhancements:

- Multi-Sensor Integration: Incorporating multispectral imaging and LiDAR data to enhance feature extraction and depth analysis.
- Dataset Expansion: Augmenting the training corpus with diverse archaeological landscapes to improve model generalization and robustness.
- Geospatial Visualization: Integrating GIS (Geographic Information System) tools to provide precise, georeferenced spatial mapping.
- Cloud Scalability: Migrating the architecture to cloud infrastructure to facilitate the high-throughput processing of large-scale datasets.
- Temporal Monitoring: Implementing longitudinal analysis capabilities to track site degradation and environmental changes over time.