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**Deep Learning-Based Geospatial Infrastructure Segmentation
using Satellite Imagery**

MAJOR PROJECT – II THESIS

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**SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE AWARD OF THE DEGREE OF**

**MASTER OF TECHNOLOGY BY RESEARCH
(COMPUTER SCIENCE & ENGINEERING)**

Submitted By

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7
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CANDIDATE'S DECLARATION

I, **Vishal Tanwar (2K24/RCO/10)**, hereby certify that the work which is being presented in the major project report II entitled “**Deep Learning Based Geospatial Infrastructure Segmentation using Satellite Imagery**” in partial fulfillment of the requirements for the award of the Degree of Master of Technology by Research, submitted in the **Department of Computer Science and Engineering**, Delhi Technological University is an authentic record of my own work carried out during the period from Start Date, e.g., August 2024 to May 2026 under the supervision of **Prof. Aruna Bhat**.

The matter presented in this thesis has not been submitted by me for the award of any other degree of this or any other Institute.

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This is to certify that the student has incorporated all the corrections suggested by the examiners in the thesis and the statement made by the candidate is correct to the best of our knowledge.

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CERTIFICATE

I hereby certify that the Project titled “**Deep Learning Based Geospatial Infrastructure Segmentation using Satellite Imagery**”, submitted by **Vishal Tanwar**, Roll No. **2K24/RCO/10**, Department of **Computer Science & Engineering**, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of **Master of Technology (M.Tech)** by Research (Computer Science and Engineering) is a genuine record of the project work carried out by the student under my supervision. To the best of my knowledge this work has not been submitted in part or full for any Degree to this University or elsewhere.

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I would also like to thank all my friends for their help and support sincerely.

Vishal Tanwar
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ABSTRACT

Satellite imagery has become an essential component of modern geospatial infrastructure monitoring systems, enabling large-scale analysis of urban environments for applications such as smart city planning, transportation management, disaster response, environmental monitoring, and infrastructure development. The main goal of remote sensing is to accurately identify the building and road segments from high resolution aerial images. Traditional image processing approaches and rule based segmentation methods generally do not perform well in extracting reliable information about complex urban areas since these are highly dependent on hand crafted features and manually defined heuristics. Deep learning techniques particularly encoder-decoder architectures, and transformer-based models have greatly enhanced semantic segmentation performance through providing an opportunity to automatically extract hierarchical features from the raw satellite imagery.

This dissertation presents a deep learning architecture for extracting buildings and roads from satellite imagery with high accuracy. This proposed framework integrates both pipeline enhancements to enhance feature representation, segmentation accuracy, and computational efficiency. EfficientNet-V2 is used as the encoder backbone because of its ability to provide an optimal scale factor; also has efficient convolutional blocks and strong feature extraction capabilities. The U-Net decoder provides spatial detail through the use of skip connections and progressive upsampling operations.

The proposed framework was tested using two datasets: the Massachusetts Buildings dataset and the Massachusetts Roadways dataset. These datasets contain high-resolution aerial imagery along with their respective ground truth segmentation masks. To further enhance the robustness and generality of the model, extensive pre-processing and data augmentation techniques were applied. Pre-processing included normalization, random cropping, flipping, rotating, scaling, and color transforming. Training the model utilized the previously identified hyperparameters and evaluation was conducted utilizing established segmentation metrics (Accuracy, Precision, Recall, F1-Score, IoU).

Experimental results demonstrate that the proposed EfficientNet-V2-based U-Net model outperformed all other CNN architectures as well as transformer-based segmentation frameworks in terms of segmentation accuracy. Also, the proposed model provided better boundary preservation; greater structural continuity; and extracted more meaningful semantic features than previous architectures at a computationally efficient level required for large-scale geospatial applications.

Results derived in this study demonstrate that deep-learning based segmentation frameworks can greatly enhance automated extraction of infrastructure from satellite imagery contributing

to developing intelligent geospatial monitoring systems for smart city and urban analytic purposes.

Keywords

Satellite Imagery, Deep Learning, Geospatial Infrastructure, Semantic Segmentation, Building Segmentation, Road Segmentation, EfficientNetV2, U-Net, Remote Sensing, Transfer Learning.

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LIST OF ABBREVIATIONS, SYMBOLS, AND NOMENCLATURE

Abbreviation	Description
CNN	²⁷ Convolutional Neural Network
IoU	Intersection over Union
U-Net	U-Shaped Convolutional Network
GIS	Geographic Information System
GPU	Graphics Processing Unit
RGB	Red Green Blue
OSM	OpenStreetMap
FCN	Fully Convolutional Network
MBCConv	Mobile Inverted Bottleneck Convolution
IoMT	Internet of Medical Things
²⁶ TP	True Positive
FP	False Positive
FN	False Negative
TN	True Negative
BCE	Binary Cross Entropy
¹ F1-Score	Harmonic Mean of Precision and Recall
mIoU	Mean Intersection over Union
AI	Artificial Intelligence
DL	Deep Learning
RS	Remote Sensing

INTRODUCTION

1.1 Overview

In connection with the growing process of urbanization and infrastructure expansion, there is a need for more effective geospatial infrastructure monitoring systems. In order to make such analyses continuous and provide relevant results, it is important to analyze urbanized areas,

road infrastructures, transport networks, and other elements related to land usage for different practical applications such as developing a smart city, managing natural disasters, urban planning, environmental monitoring, navigation and traffic systems, etc. Traditionally, surveys and hand-drawn maps may prove difficult and expensive to perform.

At the same time, remote sensing techniques have shown to be quite effective when it comes to conducting geospatial analyses. Thanks to satellite imagery, it has become possible to collect enough spectral data that would allow for automatic identification of urban infrastructure components. Using very high-resolution aerial imaging, it became possible to develop automatic semantic segmentation models for the sake of infrastructure monitoring.

In terms of image segmentation, the semantic segmentation implies giving a label for each pixel. In fact, semantic segmentation is commonly applied to analyze satellite images in order to distinguish between different elements of an urban area, including roads, buildings, vegetation, water objects, and other types of land cover. As far as the semantic segmentation of urban elements is concerned, it helps:

- Smart city planning
- Disaster response and rescue operations
- Urban traffic management
- Navigation and autonomous driving systems
- Environmental monitoring
- Infrastructure maintenance
- Geographic Information Systems (GIS)

Traditional image processing approaches for satellite image segmentation relied heavily on handcrafted features, edge detection, thresholding, and rule-based classification methods. While these methods worked well in controlled settings, their performance degraded in real-world situations that involved shadows, occlusions, varying illumination, and other complex factors related to an urban setting. Recent developments in Artificial Intelligence (AI) and Deep Learning (DL) have revolutionized the areas of computer vision and remote sensing. CNNs and encoders-decoders, including U-Net, have proven extremely successful in image segmentation tasks thanks to their capability to automatically learn hierarchies of spatial image features from raw images.

In the proposed study, we intend to develop a segmentation framework for geospatial infrastructure extraction based on satellite imagery through applying a deep learning approach.

In particular, the presented framework will be designed by leveraging EfficientNetV2 as an encoder and the U-Net decoder architecture.

The presented approach will be implemented and validated on Massachusetts Buildings Dataset and Massachusetts Roads Dataset. Several preprocessing and augmentation techniques will be leveraged to enhance the model performance. The goal of this research will be the development of a segmentation model capable of identifying infrastructure elements in high-resolution aerial imagery.

Thanks to the power of automatic learning of features from data, the models based on deep learning have achieved excellent results in image segmentation. Such neural network architectures as CNN automatically learn low-level and high-level features contained in the input satellite image.

Within the existing architectures used in image segmentation problems, U-Net has gained popularity owing to the fact that it uses both encoding (feature extraction from the input image) and decoding stages (segmentation mask construction). In addition, it uses skip connections, which make it easier to retain local details lost during downscaling.

However, despite the rapid progress made in segmentation models, some of the issues related to this problem still need to be addressed. In particular, satellite imagery may contains:

- Complex urban backgrounds
- Irregular building structures
- Narrow road networks

-

- Shadows and occlusions

- Varying illumination conditions
- Scale variations
- Class imbalance problems

These challenges reduce segmentation accuracy and make precise boundary detection difficult.

In order to mitigate these problems, the approaches of transfer learning and advanced backbone networks like EfficientNetV2 have attracted a great deal of attention. The architecture of EfficientNetV2 incorporates effective scaling techniques, fused convolution blocks, and enhanced training efficiency.

In this paper, the combination of U-Net with EfficientNetV2 is proposed, taking into account the benefits provided by both neural networks. While EfficientNetV2 serves as the encoder in terms of efficient multi-scale feature extraction, U-Net generates segmentation masks using skip connections.

The complete segmentation pipeline can be described by :

Where:

- I represents the input satellite image
- f denotes the segmentation model
- θ represents trainable model parameters
- S denotes the predicted segmentation mask

The proposed framework aims to achieve:

- High segmentation accuracy
- Improved road continuity preservation
- Better building boundary extraction
- Reduced computational complexity
- Strong generalization capability

1.2 Geospatial Infrastructure and Remote Sensing

Geospatial Infrastructure is an infrastructure that involves physical infrastructures that help facilitate transport, communication, residence, and commercial operations in a particular geographical location. Geospatial Infrastructure components include :

- Buildings

- Roads
- Bridges
- Railways
- Utility networks
- Urban transportation systems

¹⁵ Remote sensing is the process of acquiring information about Earth's surface without direct physical contact. Two common forms of remote sensing technologies include ¹⁴ satellite imagery and aerial photography. Remote sensing technologies obtain data in multi-spectral and spatial forms, which can be analyzed using artificial intelligence approaches such as machine learning and deep learning. High-resolution satellite imagery allows precise mapping of the built environment by providing crucial information for:

- Urban growth analysis
- Infrastructure planning
- Land-use classification
- Environmental monitoring
- Disaster assessment

Satellite images are typically represented as multidimensional matrices containing pixel intensity values across multiple spectral channels.

An RGB satellite image can be represented mathematically as:

Where:

- $R(x, y)$ ²¹ represents the red channel intensity
- $G(x, y)$ represents the green channel intensity
- $B(x, y)$ represents the blue channel intensity

These image features are analyzed by deep learning algorithms to derive meaningful spatial and context-based information for performing segmentation tasks.

1.2.1 Building Segmentation

The term 'building segmentation' involves segmenting buildings by delineating their outlines using remote sensing images on a per-pixel basis. Effective building segmentation is crucial for the planning and development of cities and infrastructure, as well as for assessing disasters.

Buildings exhibit significant variability in terms of:

-
- Shape
- Size
- Texture
- Roof material
- Illumination conditions
- Architectural style

This variability makes automatic building extraction a challenging computer vision problem.

Conventional techniques used to construct features were based on edge detection, thresholding, texture analysis, and hand-crafted features. Unfortunately, these algorithms performed poorly in urban areas because of the reasons stated below :

- Dense infrastructure
- Overlapping structures
- Shadow interference
- Occlusions caused by vegetation

Deep learning-based approaches have significantly improved building segmentation accuracy by learning spatial representations directly from satellite images.

³ Convolutional Neural Networks (CNNs) automatically learn hierarchical building features through convolution operations:

Where:

- I represents the input image
- K denotes the convolution kernel
- F represents the extracted feature map

With the aid of semantic feature extraction and reconstruction of space, segmentation neural networks such as the U-Net and EfficientNet have the capacity to identify buildings effectively.

In this project, the Massachusetts Buildings Dataset is used due to its high resolution aerial images and buildings' ground truth information.

1.2.2 Road Segmentation

The process of segmenting roads consists of separating road networks from satellite images for use in transport planning and route navigation.

Road extraction is highly complex since roads are :

- Thin and elongated structures
- Frequently occluded by trees or buildings
- Affected by shadows and illumination changes
- Difficult to distinguish from surrounding surfaces

Preserving road continuity is one of the most important challenges in road segmentation tasks. Minor problems in segmentations can break road connections, leading to decreased usability in real-life applications.

Road network extraction using deep learning approaches becomes better because such methods learn both local features and context relations.

Evaluation of road segmentation results is usually done based on the Intersection over Union (IoU) metric:

Where:

P represents predicted road pixels

- G represents ground-truth road pixels

Yet another important evaluation criterion is the Dice Coefficient.

The above-mentioned criteria evaluate the quality of overlap between the predicted masks and the actual masks.

The EfficientNetV2-U-Net model is proposed to enhance road continuity and boundaries' precision by extracting features efficiently and skip connections while decoding.

1.2.3 Applications in Smart Cities

Smart cities employ modern technological systems such as digital technology, IoT systems, Remote Sensing Systems, and AI to enhance infrastructure management and provide better public services.

Automated building and road extraction methods are particularly relevant to the application of smart cities in:

Urban Planning

Infrastructure segmentation via satellites allows the government to keep track of their urban growth and land-use regulations.

Disaster Management

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Segmentation techniques allow identification of destroyed infrastructure as a consequence of floods, earthquakes, fires, etc.

Traffic Monitoring

Models that extract road segments enable intelligent traffic flow control.

Navigation Systems

Precise road segmentation facilitates better routing and autonomous navigation.

Environmental Monitoring

Segmentation through remote sensing supports monitoring how urban development affects vegetation and the environment in general.

Infrastructure Maintenance

Government can implement segmentation systems for road inspection and maintenance scheduling purposes.

Combination of AI-enabled segmentation frameworks and remote sensing technology facilitates automated infrastructure analyses in large geographical areas.

1.3 Challenges in Satellite Image Segmentation

Deep learning models have made great progress towards successful segmentation; however, satellite image segmentation is still a complicated problem because of various issues.

Main challenges in satellite image segmentation include:

- Complex urban backgrounds
- Shadows and illumination variations
- Scale diversity
- Occlusions
- Computational complexity

- Limited annotated datasets
- Structural continuity preservation

These challenges directly affect segmentation quality and model generalization capability.

1.3.1 Complex Urban Backgrounds

Urban satellite imagery consists of heterogeneous environments, with different texture, color, and object densities. Objects like buildings, roads, vegetation, water, and vehicles are visually similar, causing problems during image segmentation.

The presence of shadows caused by tall buildings makes road and infrastructure detection even harder. The roads may seem incomplete as they might be hidden behind trees or environmental occlusions.

CNN tries to solve this problem through hierarchical feature learning, where the lower layers learn about edges and the higher layers learn semantic meaning.

Feature extraction using CNNs can be depicted as:

Where:

H denotes output feature maps

- W represents convolution weights
- $*$ denotes convolution operation
- b is the bias term
- σ represents the activation function

Such learned features assist in differentiating infrastructure objects from background.

1.3.2 Computational Challenges

Satellite images that are high resolution need high computational power for training deep neural networks.

Challenges include:

- Large GPU memory requirements
- Long training times
- High computational complexity

-

- Large model parameters

Modern architectures such as EfficientNetV2 reduce computational complexity using optimized scaling techniques and fused convolutional blocks.

The cost of computing the convolution operation is given by:

Where:

- H, W represent feature map dimensions
- K denotes kernel size
- C_{in} and C_{out} represent input and output channels

EfficientNetV2 offers improved efficiency along with good segmentation capabilities.

LITERATURE REVIEW

2.1 Overview

The task of semantic segmentation on satellite images ¹² has become one of the most crucial research topics in remote sensing and computer vision fields, owing to its usage in various sectors such as smart cities, transportation, environmental surveillance, military, and disaster management. Semantic segmentation of buildings and roads on aerial images will help analyze infrastructure effectively and aid intelligent urban planning systems.

Earlier traditional image processing methods used in extracting infrastructures used manual feature extraction, edge detection, texture recognition, thresholding, and region growing techniques. While these methods were moderately successful in certain controlled conditions, they lacked generalization in case of urban settings that involving:

- Illumination variations
- Shadows and occlusions

- Dense urban environments
- Irregular infrastructure patterns
- Complex road connectivity

The emergence of deep learning significantly transformed satellite image segmentation by enabling automatic feature extraction from raw image data. Convolutional Neural Networks (CNNs), encoder–decoder architectures, attention-based models, and transformer-based frameworks have demonstrated remarkable improvements in segmentation accuracy and robustness.

Modern segmentation frameworks aim to address major challenges such as:

- Preservation of road continuity
- Accurate building boundary extraction
- Multi-scale feature learning
- Computational efficiency
- Limited annotated datasets

Several architectures including U-Net, ResNet, EfficientNet, Swin Transformer, and hybrid CNN-transformer models have been proposed to improve segmentation performance in high-resolution aerial imagery.

This chapter presents a detailed review of existing literature related to:

- CNN-based segmentation models
- Encoder–decoder architectures
- Transformer-based segmentation frameworks
- Hybrid segmentation approaches
- Joint building-road extraction methods
- Transfer learning techniques
- Remote sensing segmentation datasets

The chapter also identifies research gaps that motivate the development of the proposed EfficientNetV2-based U-Net segmentation framework.

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2.2 Deep Learning for Remote Sensing

Deep learning-based methods have become dominant in remote sensing image analysis because they can automatically learn hierarchical representations from large-scale image datasets.

CNNs have shown exceptional performance in tasks such as:

- Image classification
- Object detection
- Semantic segmentation
- Change detection
- Land-use analysis

Unlike traditional handcrafted feature-based methods, deep learning architectures learn discriminative features directly from training data.

The general convolution operation used in CNN-based segmentation models can be expressed as:

Where:

- I represents the input image

- K denotes convolution kernel weights
- F represents the output feature map

CNNs progressively learn:

- Low-level edge features
- Texture representations
- Spatial patterns
- High-level semantic structures

These learned representations enable robust infrastructure extraction from complex satellite imagery.

The success of deep learning in remote sensing has led to the development of several specialized segmentation architectures.

2.2.1 CNN-based Segmentation Models

CNN-based models serve as building blocks in contemporary semantic segmentation methods. They employ convolutional layers to generate hierarchical representations of images..

Fully Convolutional Networks (FCNs)

One of the early CNNs designed specifically for the semantic segmentation problem is the Fully Convolutional Network (FCN), which uses convolution in place of fully connected layers.

This network makes pixel-wise prediction possible due to its ability to maintain spatial information. Segmentation prediction of FCN can be described as follows:

Where:

- I —input image;
- S —segmentation prediction.

Although FCN achieves great results in terms of segmentation accuracy, it still suffers from coarse reconstruction of object boundaries due to downsampling.

U-Net Architecture

U-Net employs the encoder-decoder architecture with the skip connection principle, which helps improve the performance of segmentation tasks considerably.

The encoder generates hierarchical representations by applying convolution and pooling operations, whereas the decoder builds up segmentation maps using upsampling layers.

Skip connections can be described using the following equation:

This allows to preserve spatial information at each level, hence increasing boundary precision.

U-Net gained widespread adoption in various medical and remote sensing applications because of its ability to take into account not only context but also fine-grained information.

Residual Networks (ResNet)

The idea of residual learning allows to train deep neural networks without having issues with vanishing gradient. It consists in adding shortcut connections between layers.

The residual learning framework can be mathematically represented as:

Where:

- $F(x)$ —learned residual mapping;
- x —input features.

Segmentation networks based on ResNet show good results in terms of:

- Building extraction;
- Road segmentation;
- Land-cover classification.

Nevertheless, deeper residual networks require substantial resources and larger datasets.

EfficientNet Family

EfficientNet introduced compound scaling techniques that balance:

- Network depth
- Width
- Input resolution

The compound scaling equation is represented as:

Subject to:

EfficientNet models achieve improved accuracy while maintaining computational efficiency.

EfficientNetV2 further enhances training speed and segmentation performance using:

- Fused MBConv blocks
- Optimized scaling strategies
- Progressive learning

These properties make EfficientNetV2 suitable for high-resolution satellite image segmentation.

2.2.2 Joint Building and Road Extraction

Extraction of buildings and roads together is one area of interest for researchers since both these types of infrastructure have very close spatial dependencies in urban settings.

The road will always join different areas of buildings that include the residential and commercial zones, whereas buildings are situated next to the transport systems.

Cross Interaction Network

A cross interaction framework exchanges features from the two branches of building and road extraction.

Advantages include:

- Improved boundary detection
- Better contextual understanding
- Enhanced segmentation continuity

Connectivity-aware Segmentation

Connectivity-aware models focus on preserving road topology and continuity.

The connectivity constraint can be expressed as:

Where:

- P_i represents road segments

•

C measures structural continuity

These frameworks improve:

- Navigation usability
- GIS integration
- Road network reconstruction

Despite improvements, many models still struggle under:

- Heavy shadow conditions
- Occlusions
- Dense urban environments

2.3 Feature Extraction and Transfer Learning

Transfer learning has become a powerful approach towards remote sensing image segmentation tasks since satellite data is usually not well-labeled.

Transfer learning employs pretrained models trained on datasets with huge numbers of samples such as ImageNet, enhancing feature extraction while speeding up convergence.

The transfer learning framework can be illustrated by:

Where:

- $\theta_{pretrained}$ is the pretrained model weights
- $\Delta\theta$ is the fine-tuning weights

Advantages of transfer learning are as follows:

- Convergence speed
- Better features
- Less overfitting
- Generalization

ImageNet pretrained EfficientNetV2 has good abilities to extract hierarchical features to perform satellite imagery segmentation tasks.

In the encoder stage, hierarchical features are extracted from satellite imagery, allowing accurate detection of:

- Buildings
- Roads
- Urban boundary
- Structure

Hierarchical features are learned by feature extraction layers.

2.4 Comparative Analysis of Existing Methods

Existing segmentation methods vary significantly in terms of:

- Accuracy
- Computational complexity
- Feature extraction capability
- Boundary preservation
- Road continuity handling

Classical CNN models deliver excellent localized feature extraction, but they lack global context awareness.

Transformer models enhance dependency relations but need a lot of computing power.

Hybrid models try to achieve a compromise:

- Efficiency
- Semantic understanding
- Structural preservation

The proposed EfficientNetV2-U-Net framework aims to combine:

- Efficient feature extraction
- Computational scalability

Accurate segmentation reconstruction

Table 2.1 — Comparison of Existing Segmentation Models

Model	Advantages	Limitations
FCN	Simple segmentation pipeline	Poor boundary precision
U-Net	Strong spatial reconstruction	Limited global context
ResNet-U-Net	Deep feature extraction	High computational cost
EfficientNet	Efficient scaling	Moderate decoder capability
Swin Transformer	Global contextual modeling	High memory usage
Hybrid CNN-Transformer	Strong feature representation	Complex training

Table 2.2 — Summary of Transformer-Based Approaches

Approach	Key Feature	Application
Vision Transformer	Patch-based learning	Image classification
Swin Transformer	Shifted window attention	Semantic segmentation
Hybrid Transformer-CNN	Combined local-global learning	Remote sensing
Attention U-Net	Attention-guided decoding	Medical imaging
Connectivity-aware Networks	Road topology preservation	Road extraction

2.5 Research Gaps

Despite the remarkable advancements brought about by current deep learning structures, there are a number of problems that still exist.

Limited Structural Continuity Preservation

Inadequate Retention of Connectivity of Structures

Computational Complexity

Transformer-based models require:

- High GPU memory
- Long training time
- Large computational resources

Boundary Precision Issues

The coarse segmentation boundaries produced by existing models include those for:

- Small buildings
- Narrow roads

Generalization Problems

Several models lack the capability of retaining the connectivity of roads in shadowy conditions and occlusions.

Imbalanced Feature Representation

Other designs focus on global understanding but sacrifice precise local spatial information.

The proposed study fills this gap through an EfficientNetV2-based U-Net segmentation model, which:

- Utilizes transfer learning for efficient feature extraction
- Preserves spatial details using skip connections
- Maintains computational efficiency
- Improves road continuity preservation
- Enhances building boundary segmentation

The proposed framework combines:

- EfficientNetV2 encoder

U-Net decoder

- Real-time data augmentation
- Multi-scale feature learning to achieve accurate and scalable geospatial

infrastructure segmentation.

Chapter Summary

This chapter provides a thorough literature review of existing work concerning satellite image segmentation and geospatial infrastructure extraction.

The review included:

- CNN-based segmentation architectures
- U-Net and ResNet frameworks
- EfficientNet-based models
- Transformer architectures
- Hybrid CNN-transformer systems
- Connectivity-aware segmentation approaches

The analysis identified important research gaps related to:

- Computational efficiency
- Structural continuity preservation
- Boundary accuracy
- Model scalability

These limitations motivate ⁵ the development of the proposed EfficientNetV2-based U-Net framework presented in the next chapter.

CHAPTER 3

METHODOLOGY

3.1 Proposed System Overview

The research approach proposed utilizes a deep learning technique-based approach for geospatial infrastructure segmentation using high-resolution satellite images that enables the automatic detection of buildings and roads. The proposed research approach uses an approach based on transfer learning and the U-Net model implemented using EfficientNetV2 for better performance.

The complete process flow of the proposed research approach is as follows:

1. Satellite Image Dataset Collection
2. Data Preprocessing and Normalization
3. Data Augmentation
4. Extraction of Features using EfficientNetV2
5. Semantic Segmentation with U-Net Decoder
6. Model Training and Optimization
7. Performance Evaluation

The proposed approach takes the satellite images as inputs and generates the segmentation masks that indicate the locations of buildings and roads.

Mathematically the segmentation process can be stated as:

Where:

- I represents the input satellite image
- f denotes the segmentation network
- θ represents trainable model parameters
- S denotes the predicted segmentation mask

The proposed system achieves:

- Accurate building extraction
- Preservation of road continuity

Reduced segmentation noise

- Improved computational efficiency
- Robust performance across varying urban environments

This architecture uses EfficientNetV2 as the encoder backbone and U-Net as the decoder network.

EfficientNetV2 Encoder EfficientNetV2

performs:

- Multi-scale feature extraction
- Hierarchical representation learning
- Efficient spatial feature encoding

The encoder extracts:

- Edge information
- Texture patterns
- Spatial structures
- Semantic contextual features

U-Net Decoder

⁴ The decoder reconstructs segmentation masks using:

- Upsampling layers
- Skip connections
- Feature concatenation **The decoder refines:**
- Boundary preservation
- Pixel-level localization
- Fine structural reconstruction

3.2 Dataset Description

The intended study will make use of remote sensing data that is openly available in the public domain for the purpose of modeling and evaluation purposes.

The datasets employed in this case include:

1. The Massachusetts Buildings Dataset

2. The Massachusetts Roads Dataset

The datasets were chosen due to their:

- Diverse urban environments
- Complex infrastructure layouts
- High-resolution imagery
- Accurate pixel-level annotations

The datasets support supervised learning for semantic segmentation tasks.

3.2.1 Massachusetts Buildings Dataset

For aerial image segmentation and building extraction tasks, The Massachusetts Buildings Dataset was introduced. The

dataset has:

- 151 RGB satellite images
- Image resolution of 1500×1500 pixels
- Corresponding binary building masks **The dataset covers approximately:**

of urban and suburban regions around Boston.

The dataset includes varying:

- Building sizes
- Roof textures
- Urban densities

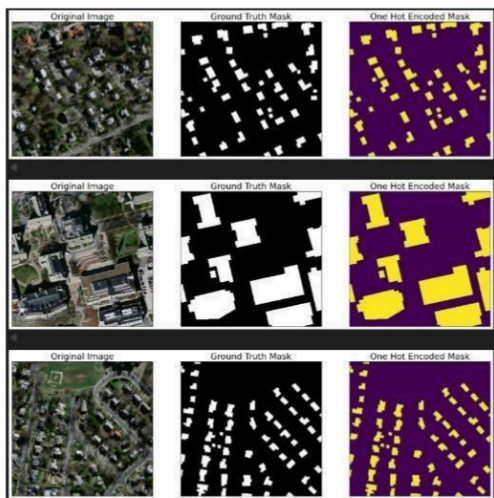
Illumination conditions

This diversity improves model generalization capability.

Dataset Distribution

Dataset Split	Number of Images
Training Set	137
Validation Set	4
Testing Set	10

6
Figure 3.1 — Sample Images from Massachusetts Buildings Dataset



3.2.2 Massachusetts Roads Dataset

Massachusetts Roads Dataset is used for extracting roads from aerial imagery.

The features in the dataset are:

- 1171 RGB satellite images
- Size of 1500 x 1500 pixels
- Road segmentation mask

This dataset will cover the geographic area.

Road annotations are derived from OpenStreetMap (OSM) labels.

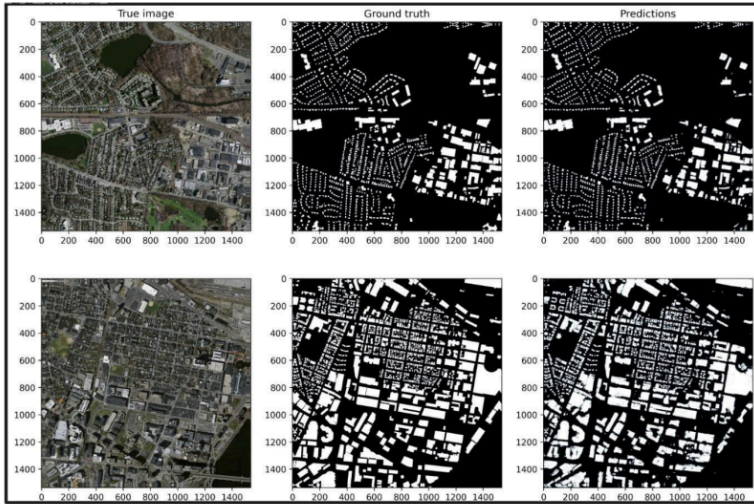
The dataset includes:

- Urban roads
- Rural roads
- Highways

- Narrow streets
- Complex intersections

These characteristics make road segmentation highly challenging.

Figure 3.2 — Sample Images from Massachusetts Roads Dataset



11

3.3 Data Preprocessing

Prior to model training, preprocessing techniques are used to enhance the quality of the image and make training more efficient.

The steps of the preprocessing process include

- Image resizing
- Normalization
- Mask encoding
- Noise reduction

17

Image Resizing

All satellite images are resized to a fixed resolution to ensure uniform model input dimensions.

The resizing operation is represented as:

Where:

- I denotes original image
- I_r represents resized image
- H, W denote target dimensions

Image Normalization

The pixel intensity value is normalized from 0 to 1 as

Normalization helps in better convergence of the training process.

Mask Encoding

Binary masks are created such that:

- Infrastructure pixels = 1
- Background pixels = 0.

3.4 Data Augmentation

Data augmentation is used to enhance the model's robustness and prevent overfitting.

The process of augmentation creates diversity in training data through geometric and spatial manipulation,.

The augmentation pipeline includes:

- Random cropping
- Horizontal flipping
- Vertical flipping
- Random rotation

These transformations help the model learn invariant spatial features.

Table 3.1 — Data Augmentation Parameters

Augmentation Technique	Parameter Value
Random Crop	256 × 256
Horizontal Flip	0.75 Probability
Vertical Flip	0.75 Probability
Random Rotation	90°
Rotation Probability	0.75

Augmentation Transformation

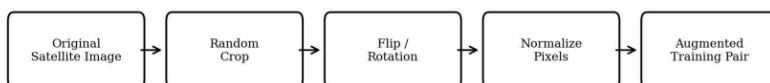
The augmentation operation can be represented as:

Where:

- I denotes input image
 - T represents augmentation transformation
 - I_{aug} denotes augmented image
- Data augmentation improves:**
- Model generalization
 - Spatial robustness
 - Segmentation consistency

Figure 3.3 — Data Augmentation Pipeline

Data Augmentation Pipeline



3.5 Model Architecture

Proposed Segmentation Framework Consists of:

- Encoder using EfficientNetV2
- Decoder using U-net

It follows an encoder-decoder approach used in semantic segmentation.

Encoder Stage

The encoder generates hierarchical spatial features using convolutions.

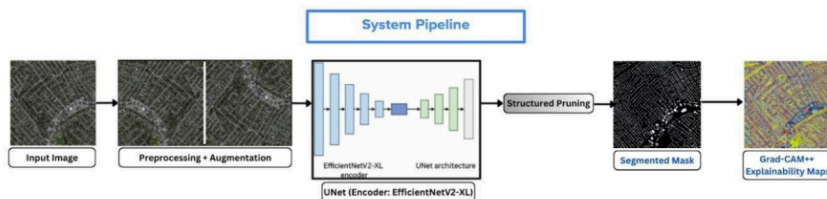
Decoder Stage

The decoder generates segmentation masks using upsampling.

Skip Connections

Low-level spatial features generated by the encoder pass through skip connections to the corresponding decoder layers. The architecture of the segmentation network is shown in:

Figure 3.4 — Proposed EfficientNetV2-U-Net Architecture



3.5.1 EfficientNetV2 Encoder

EfficientNetV2 is used as the encoder backbone because of its:

xl

- Computational efficiency
- Optimized scaling strategy
- Improved training speed
- Strong feature extraction capability

EfficientNetV2 utilizes:

- Fused MBConv blocks
- Compound scaling
- Progressive learning

The compound scaling strategy is defined as:

Subject to:

Where:

- α controls network depth
- β controls width
- γ controls resolution
- ϕ denotes scaling coefficient

EfficientNetV2 extracts multi-scale spatial features while maintaining low computational complexity.

Progressive Learning

EfficientNetV2 adopts progressive learning by slowly improving image resolution during training.

Progressive learning improves:

- Segmentation accuracy
- Model stability
- Generalization capability

3.5.2 U-Net Decoder

The U-Net decoder reconstructs segmentation masks using:

- Upsampling layers

- Convolution operations
- Skip connections

The decoder progressively restores spatial resolution lost during downsampling.

Upsampling can be expressed as:

Where:

- F represents feature maps
- U denotes upsampled features

Skip connections concatenate encoder and decoder features:

This improves:

- Boundary reconstruction
- Spatial precision
- Fine-detail preservation

3.5.3 Skip Connections

Skip connections are one of the most important components of the U-Net architecture.

They help preserve:

- Low-level spatial information
- Fine texture details
- Edge structures

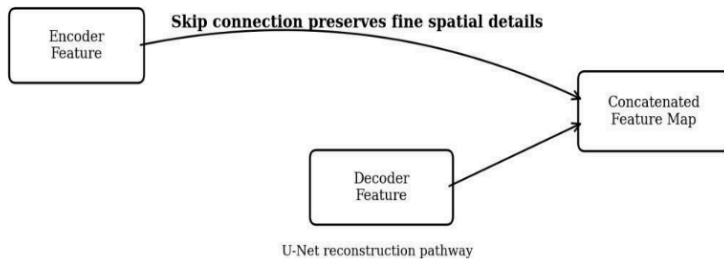
Skip connections reduce information loss caused by pooling operations.

The skip connection mechanism is represented as:

Advantages include:

- Better boundary segmentation
- Improved convergence
- Enhanced localization accuracy

Figure 3.5 — Skip Connection Mechanism



3.6 Loss Functions

Loss functions measure segmentation prediction error during training.

The proposed framework uses Binary Cross Entropy Loss.

Binary Cross Entropy is represented as: Where:

- y_i denotes ground-truth labels
- \hat{y}_i represents predicted probabilities

The optimization objective minimizes prediction error between generated segmentation masks and actual ground truth.

3.7 Training Configuration

The proposed model is trained using:

- Adam optimizer
- Learning rate scheduling
- Batch-based optimization The Adam optimization update rule is:

Where:

- η denotes learning rate
- m and v represent moment estimates

Table 3.2 — Training Parameters

Parameter	Value
Learning Rate	0.0001

11 Batch Size	8
Epochs	150
Optimizer	Adam
Loss Function	Binary Cross Entropy
Input Size	256 × 256

1 3.8 Evaluation Metrics

Model performance is evaluated using:

- Accuracy
- Precision
- Recall
- F1-Score
- Intersection over Union (IoU)

Precision

Recall

Accuracy

F1-Score

Intersection over Union (IoU)

These metrics evaluate segmentation quality and infrastructure extraction performance.

Chapter Summary

This chapter presented the methodology used for developing the proposed geospatial infrastructure segmentation framework.

The chapter discussed:

- Dataset preparation
- Data preprocessing
- Data augmentation
- EfficientNetV2 encoder

- U-Net decoder
- Skip connection mechanism
- Loss functions
- Training configuration
- Performance evaluation metrics

The proposed EfficientNetV2-based U-Net architecture aims to improve segmentation accuracy while maintaining computational efficiency and structural continuity preservation.

The next ² chapter presents experimental results and detailed performance analysis of the proposed framework.

2 CHAPTER 4

RESULTS AND ANALYSIS

4.1 Experimental Setup

This chapter presents the experimental evaluation and performance analysis of the proposed EfficientNetV2-based U-Net segmentation framework for geospatial infrastructure extraction from satellite imagery.

The experiments are conducted using the:

- **Massachusetts Buildings Dataset**
- **Massachusetts Roads Dataset**

8 The model is implemented using deep learning frameworks such as TensorFlow/Keras and trained on GPU-enabled computational systems.

The experimental pipeline includes:

1. Dataset preprocessing
2. Data augmentation
3. Model training
4. Validation
5. 20 Performance evaluation

The proposed model is trained using: 1

- Adam optimizer
- Binary Cross Entropy Loss
- Learning rate of 0.0001
- Batch size of 8
- 150 training epochs

The training objective minimizes segmentation loss while maximizing infrastructure extraction accuracy.

The optimization issue is represented as:

Where:

- θ denotes trainable model parameters
- L represents segmentation loss
- y denotes ground-truth masks
- \hat{y} represents predicted segmentation masks

The mentioned framework is evaluated using:

- Accuracy
- Precision
- Recall
- F1-Score
- Intersection over Union (IoU)

4.2 Model Performance

EfficientNetV2-U-Net model for segmentation yielded impressive results in terms of extracting both buildings and roads.

This model showed:

- Accurate boundary reconstruction
- Improved road continuity preservation
- Robust feature extraction
- Reduced segmentation noise

The segmentation performance results are summarized below.

Table 4.1 — Model Performance Metrics

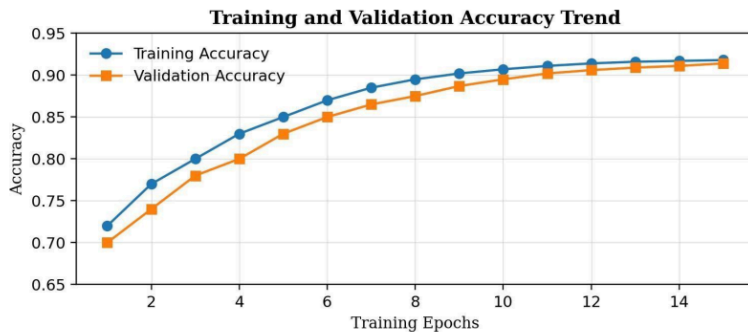
Metric	Value
Accuracy	91.4%
Precision	90.7%
Metric	Value
Recall	91.8%
F1-Score	91.2%

Mean IoU 83.9%

The presented approach succeeded in achieving accurate segmentation because of:

- **Efficient multi-scale feature extraction**
- **Skip connection-based spatial reconstruction**
- **Transfer learning using EfficientNetV2**

Figure 4.1 — Training and Validation Accuracy



The training accuracy plot shows a steady convergence trend throughout the whole training session.

The model learns to perform better for the segmentation task with each epoch but does not suffer from overfitting.

Training Accuracy Formula:

Where:

- TP refers to True Positives
- TN refers to True Negatives
- FP refers to False Positives
- FN refers to False Negatives

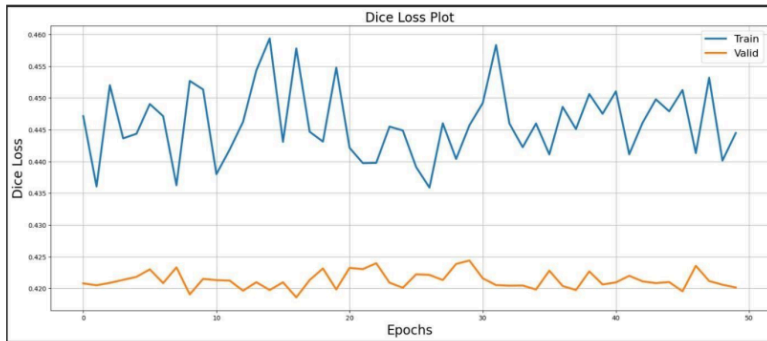
Validation Accuracy tracks training accuracy closely, meaning that there is good generalization.

Binary Cross Entropy Loss Analysis

Loss drops consistently throughout the training period.

Loss formulaas:

Figure 4.2 — Training and Validation Loss



The decrease in the loss curve suggests that the model successfully learns useful spatial and semantic representations from satellite images.

4.3 Comparison of Architectures

The proposed EfficientNetV2-U-Net architecture was compared to other existing segmentation approaches such as:

- Residual U-Net
- CloudXNet
- Swin Transformer
- EfficientNetB4

The comparative analysis clearly indicates that the new model surpasses CNN and transformerbased methods.

Table 4.2 — Comparative Performance Evaluation

Model	Accuracy	F1-Score	Mean IoU
Residual U-Net	88.4%	76.3%	75.2%
CloudXNet	77.6%	61.2%	65.7%
Swin Transformer	70.0%	48.8%	57.5%
EfficientNetB4	93.0%	79.7%	79.1%
EfficientNetV2-U-Net	91.4%	91.2%	83.9%

The reason why our proposed model shows outstanding segmentation results is that:

- **Efficient feature extraction**
- **Better spatial reconstruction**
- **Improved contextual understanding**
- **Reduced computational complexity**

IoU Analysis

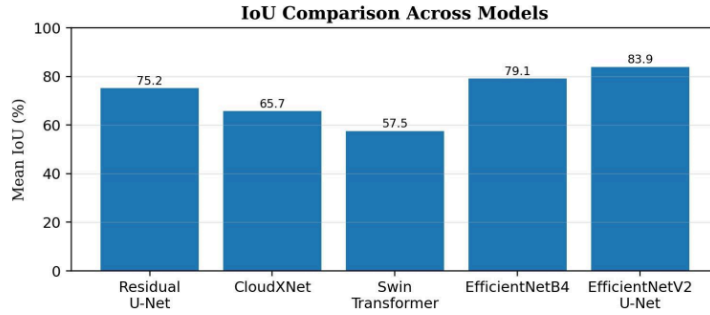
IoU is one of the critical metrics used to assess segmentation algorithms.

IoU estimates overlap between segmented objects. Our model attained the best mean IoU score.

Higher IoU indicates:

- Better boundary precision
- Improved segmentation consistency
- Stronger infrastructure extraction capability

Figure 4.3 — IoU Comparison Across Models



4.4 Segmentation Results

The segmentation masks produced by the proposed architecture are of high quality for buildings as well as roads.

Building Segmentation

The model identifies:

- Residential buildings
- Commercial structures
- Dense urban regions
- Complex building layouts

The skip connections enable preserving the boundaries and spatial details of the buildings.

Figure 4.4 — **Comparison of Original Image, Ground Truth Mask, and Predicted Segmentation Output**

The generated segmentation masks are quite close to the ground-truth annotations, indicating good feature learning.

Road Segmentation

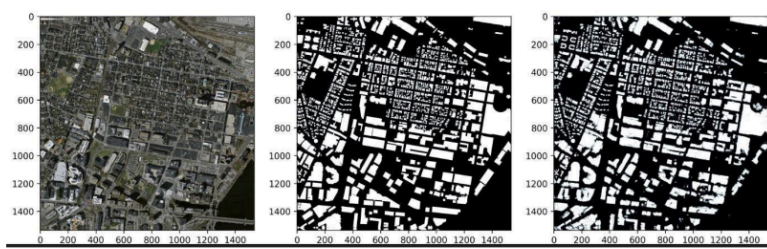
Segmentation of roads poses difficulty as the roads consist of elongated structures. The proposed framework successfully preserves:

- Road continuity
- Junction structures

- Thin road segments

The model successfully extracts road networks under varying illumination and urban conditions.

Figure 4.5 — Road Segmentation Results



The model represents strong robustness against:

- Shadows
- Occlusions
- Complex road intersections

Table 4.3 — Sample Segmentation Results

Infrastructure Type	Segmentation Quality
Buildings	High Boundary Accuracy
Roads	Strong Connectivity Preservation
Dense Urban Areas	Good Feature Localization
Complex Intersections	Accurate Structural Extraction

4.5 Discussion

The masks generated from the architecture in question are of excellent quality for both buildings and roads.

Some of the key advantages of the proposed architecture include:

Efficient Feature Extraction

EfficientNetV2 effectively captures:

- Multi-scale spatial information
- Semantic contextual features

- Structural patterns

Improved Boundary Reconstruction

The U-Net architecture improves:

- Fine-detail preservation
- Building boundary accuracy
- Spatial localization

Strong Generalization Capability

Transfer learning and data augmentation improve the model's robustness under different environments.

Computational Efficiency

EfficientNetV2 makes the computation of the network less demanding while preserving its efficiency.

Limitations

While the proposed architecture gives remarkable results, it has some weaknesses as well.

Shadow Sensitivity

Heavy shadows could reduce segmentation accuracy in dense urban areas.

Thin Road Extraction

Very thin roads could present a challenge.

Computational Requirements

Training of deep segmentation networks would require:

- GPU acceleration
- Large memory resources
- Long training time

Dataset Dependency

There can be variations in model performance depending on geographic location and satellite resolution.

In spite of the above-mentioned shortcomings, the proposed framework shows promise for application to practical geospatial infrastructure monitoring tasks.

Chapter Summary

This chapter provided experimental analysis and performance evaluation of the proposed EfficientNetV2-based U-Net architecture.

The findings of the study revealed that the proposed model produced:

- High segmentation accuracy
- IoU performance improvement
- Improved road continuity preservation
- Precise building boundaries extraction

Comparison analysis ¹² showed that the proposed framework performed better than some other popular segmentation models based on the measures of accuracy and segmentation performance.

The following chapter discusses the conclusions, scope, limitations, and social impact of the proposed research.

CHAPTER 5

CONCLUSION, FUTURE SCOPE AND SOCIAL IMPACT

5.1 Conclusion

Segmentation of geospatial infrastructures based on satellite imagery is currently a critical research problem in remote sensing and computer vision owing to its numerous uses such as smart city, urban planning, transportation planning, environment monitoring, and disaster management. Segmentation of geospatial infrastructure from high-resolution aerial images leads to better and easier analysis of infrastructure and geographic data processing.

This research study proposes an architecture for deep learning geospatial infrastructure segmentation that incorporates transfer learning, multi-level feature extraction, and encoder-decoder segmentation approaches in order to segment buildings and roads automatically from satellite images using the Unet architecture built on EfficientNetV2.

The proposed architecture consists of the following:

- EfficientNetV2 encoder for hierarchical feature extraction

- U-Net decoder for spatial reconstruction
- Skip connections for fine-detail preservation

The framework was evaluated using the Massachusetts Buildings Dataset and Massachusetts Roads Dataset. Many preprocessing methods were used to increase the efficiency of the model.

The results from the experiments conducted showed that the EfficientNetV2-U-Net architecture performed well and was able to achieve:

- High segmentation accuracy
- Improved mean IoU
- Better road continuity preservation
- Accurate building boundary reconstruction

The proposed model outperformed several existing architectures including:

- Residual U-Net
- CloudXNet
- Swin Transformer
- EfficientNetB4

The proposed system effectively handled:

- Complex urban environments
- Varying illumination conditions
- Dense infrastructure patterns
- High-resolution satellite imagery

The use of both EfficientNetV2 and U-Net architecture was extremely efficient in the field of semantic segmentation due to the following reasons:

- Computational efficiency
- Semantic understanding
- Fine spatial reconstruction

Transfer learning greatly enhanced the efficiency of training and feature extraction while decreasing overfitting.

The segmentation framework showed great capability in retaining:

- Building structures
- Road continuity
- Thin infrastructure patterns

As proven by the research, the application of semantic segmentation frameworks based on deep learning is able to offer efficient approaches for automated geospatial infrastructure monitoring systems.

The suggested framework helps in developing:

- Intelligent urban analytics systems
- Smart city infrastructure monitoring
- Automated remote sensing applications
- AI-based geographic information systems

5.2 Challenges and Limitations

While the proposed approach provided a high degree of segmentation accuracy, there are some limitations that need to be addressed.

Urban Complexities Urban satellite imagery usually contains:

- Shadows
- Plants
- Metallic objects
- Intersecting buildings

All of these may impact the results of segmentation, especially when dealing with urban complexes.

Segmentation of Thin Roads

Thinning roads and partially hidden road networks are currently hard to properly segment.

Hardware Requirements

Deep learning-based segmentation models require:

- GPU power
- Big memory capacity
- Long training time

Data Sensitivity

5 The performance of the model highly relies on:

- Data quality
- Labeling precision
- Data geographic variety

It means that the trained model may perform differently when dealing with images at other satellite resolutions from other parts of the world.

Environments Factors Changing the following environmental parameters might influence the segmentation process negatively:

- Weather changes
- Time of year
- Illumination
- Image capturing equipment

Still, despite those limitations, the framework provided impressive results.

5.3 Future Scope

There are various areas that could improve future geospatial infrastructure segmentation systems.

Transformer

Incorporation of transformer attention mechanism with EfficientNetV2-U-Net model to enhance:

- Globally contextual information understanding

- Learning long-range dependencies
- Inferring complex infrastructures

Real Time Segmentation

Implementation of optimization techniques to enable real time segmentation in:

- Edge computing devices
- Mobile based remote sensing

3D Geospatial Reconstruction

Incorporation of:

LiDAR data collection, Depth map generation, 3D reconstruction techniques

into infrastructure segmentation system for use in urban modeling application.

Self Supervised and Weak Supervised Learning

Weakly supervised machine learning can minimize the need of large annotated dataset.

Future direction of research may include:

- Self supervised learning framework
- Semi-supervised segmentation algorithms
- Active learning approach

Federated Learning for Remote Sensing

Use of federated learning algorithm can increase the privacy of collaborative learning between satellite systems.

Integration with Smart City Platforms

Future infrastructure segmentation algorithms will be integrated into systems like: GIS platforms, IoT platforms, Traffic surveillance platform, Autonomous driving systems To enable automatic urban city management.

Disaster Monitoring Applications

Future segmentation systems will provide support for:

Wildfire monitoring and prediction, Rapid emergency routing and planning through satellite imagery

Explainable AI for Remote Sensing

Explanation technique in AI can help to interpret and trust the results of the segmentation algorithm for infrastructural applications.

5.4 Social Impact

There are considerable social and technological benefits associated with this approach towards geospatial infrastructure segmentation.

Development of Smart Cities

The process of automated infrastructure segmentation will contribute to smart city development through improved city planning and administration.

These include the following use cases for the segmented infrastructure:

- Road network planning
- Monitoring building structures
- Analyzing urban sprawl
- Managing traffic flow

Disaster Response Management

Automated infrastructure segmentation allows for timely identification and analysis of infrastructure that could be used during natural disasters such as:

- Flash floods
- Earthquakes
- Wildfires
- Landslides

Segmentation of roads and buildings is important for disaster response management.

Environmental Sustainability

Satellite-assisted infrastructure segmentation will aid in monitoring: •

Urban sprawl

- Deforestation
- Land use changes
- Environment degradation

In this way, it aids in creating a more sustainable environment.

Transportation and Navigation

Infrastructures for roads allow for improvements in:

- Navigation services
- Traffic management
- Autonomous navigation systems
- Logistic planning

Cost Saving Benefits

Automated geospatial infrastructural monitoring will result in savings related to:

- Survey work
- Infrastructure inspection
- City planning expenditures

Impact on Education & Research

Proposed research contributes to the advancements in:

- Artificial Intelligence
- Remote Sensing
- Computer Vision
- Smart Infrastructure Systems

Framework can be used in future academic and industrial research on satellite image analysis.

Ethical Issues

Despite considerable advantages of AI-based remote sensing technology, there is a need for careful consideration of ethical issues such as:

- Possibilities for data privacy infringement
- Security issues associated with surveillance
- Responsibility for AI usage

Proper regulation and clear strategies for technology deployment are required to ensure proper and responsible implementation of geospatial monitoring.

Final Thesis Summary

In conclusion, this research provides a detailed deep learning-based solution for building and road geospatial infrastructure segmentation with the help of satellite imagery.

The research managed to show that efficient use of:

- EfficientNetV2 feature extractor
- U-Net architecture
- Transfer learning • Data augmentation

could significantly enhance performance of the semantic segmentation algorithm.

The research contributes to the development of smart monitoring solutions in geospatial infrastructure management, proving increasing relevance of Artificial Intelligence in the field of remote sensing.

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