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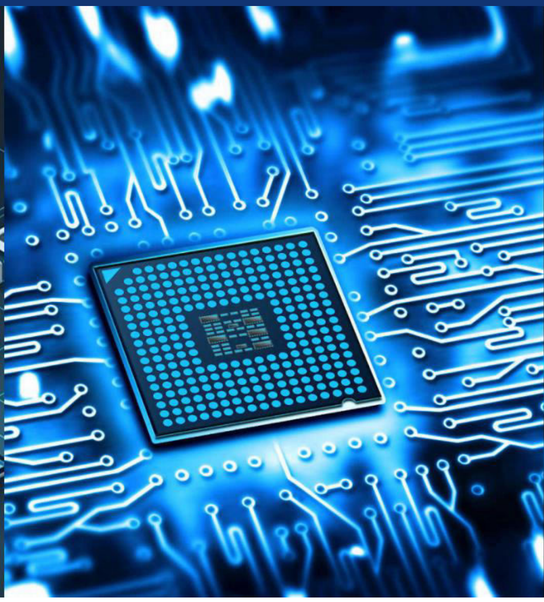

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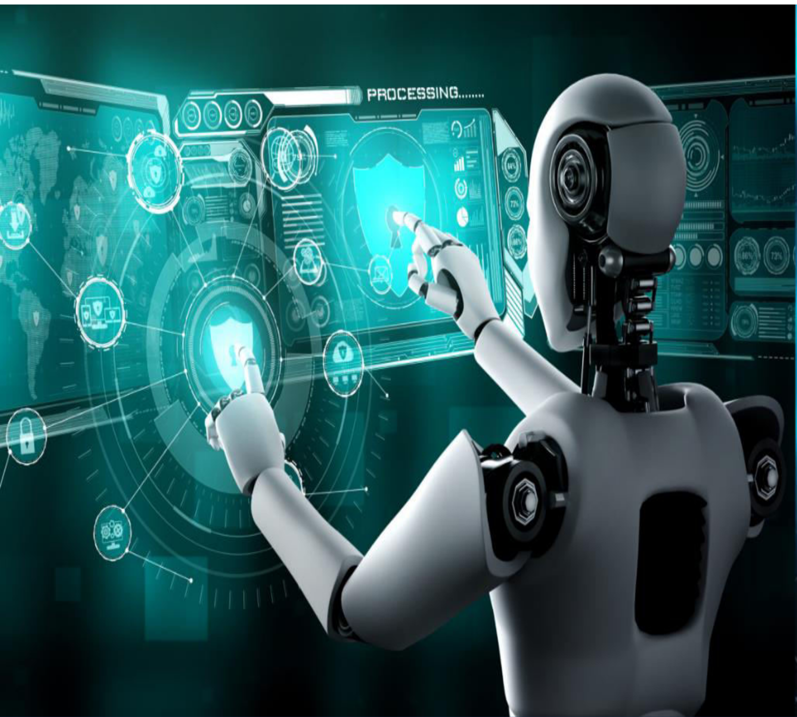

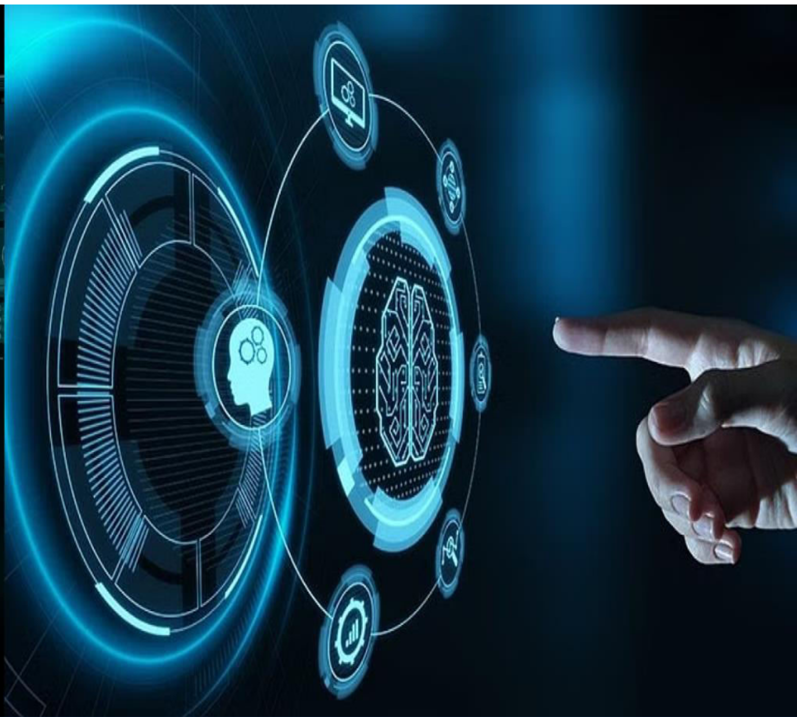

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Interactive Semantic Segmentation on Satellite

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ABSTRACT: Develop a mobile or desktop (qg is plugin) or web application that uses on-device GPU/NPU for interactive semantic segmentation on images loaded using WMS service. Challenge: To ensure the system is user-friendly and accessible, even for non-technical users. To utilize the computational power of GPUs/NPUs to enhance the performance and responsiveness of the system and reduce reliance on server side GPU compute. Usage: Useful for assisting on- screen digitization for various remote sensing applications. Users: Web GIS application developers and the end users of these applications. Available Solutions (if Yes, reasons for not using them): Individual components are available, comprehensive and proven solution does not exist. Desired Outcome: 1. The tool should be compatible with and OGC compatible WMS service 2. It should provide data export in geospatial format of user selected features (geojson / kml). 3. It should make maximum utilization of on-device GPUs/NPUs available in modern desktop/mobile devices.

KEYWORDS: Satellite Imagery, Geospatial Intelligence, On-screen Digitization, Land Use Mapping, Infrastructure Planning, Environmental Monitoring

I. INTRODUCTION

Web Map Services (WMS) are widely used for distributing geospatial data over the web. However, performing semantic segmentation on WMS data in real-time often requires powerful server-side computing, leading to high processing loads and latency. To address this, we propose a GPU/NGPU (Next-Generation Processing Unit Acceleration)-powered on-device semantic segmentation tool that enhances performance, reduces server dependency, and enables geospatial data export.

II. LITERATURE SURVEY

1. Semantic Segmentation in Remote Sensing

Semantic segmentation is a core task in remote sensing where each pixel in an image is classified into predefined categories (e.g., buildings, vegetation, water bodies). Traditional approaches rely heavily on deep learning models such as U-Net, Seg Net, and Deep Lab deployed on powerful server-side infrastructures. Studies show that while these models offer high accuracy, they are computationally intensive and require cloud-based GPUs, leading to latency and scalability issues (Zhu et al., 2017).

2. Limitations of Server-Side Processing

Server-side processing introduces network latency, high operational costs, and data privacy concerns. Research highlights the infeasibility of real-time segmentation in remote areas with poor connectivity, making cloud-based solutions inadequate for field-level applications (Mar manis et al., 2016). Furthermore, government and defense agencies seek on-device solutions to retain data sovereignty and ensure confidentiality (Li et al., 2019).

3. GPU/NPU Acceleration for On-Device Computing

Recent advancements in GPU and NPU hardware in consumer devices (e.g., smartphones, laptops) enable real-time,

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on-device AI computation. Literature reveals that frameworks like TensorFlow Lite, ONNX Runtime, and Web GPU/WebGL can harness these processing units for accelerated image analysis (Howard et al., 2019). Studies confirm that on-device inference significantly reduces energy consumption and improves responsiveness while eliminating dependency on servers (Han et al., 2020).

4. Web Map Service (WMS) Integration

WMS is a standard protocol for serving georeferenced map images over the internet. While WMS is widely used in GIS applications, integrating real-time semantic segmentation directly on WMS-loaded images is relatively unexplored in existing literature. Current solutions mainly involve static overlays or pre-processed datasets (OGC Standards, 2018). There is a gap in dynamic, real-time interaction with WMS images using on-device processing tools.

5. **User-Centric Design and Accessibility**

Literature emphasizes the importance of user-friendly interfaces, particularly for non-technical users. Studies show that incorporating voice commands, touch-based interactions, and adaptive interfaces enhances usability and adoption in diverse user groups (Shneiderman, 2020). Despite advancements, interactive segmentation tools for the general public, integrated with WMS and GPU acceleration, remain underdeveloped.

6. **Existing Tools and Gaps**

Tools like QGIS, ArcGIS, and Google Earth Engine offer some level of segmentation and analysis but rely on external computation and lack real-time responsiveness on standard devices. Research points to modular solutions for segmentation and limited support for on-device GPU/NPU processing (Qi et al., 2017).

III. PROBLEM STATEMENT

Satellite imagery plays a vital role in various sectors, including remote sensing, urban planning, disaster management, and environmental monitoring. A critical task in these applications is semantic segmentation, which involves classifying each pixel in an image into meaningful categories (e.g., buildings, vegetation, water bodies). Currently, semantic segmentation of satellite images—especially those accessed through Web Map Services (WMS)—relies heavily on server-side processing using high-performance GPU servers. This approach presents significant challenges:

- High server load and operational cost
- Latency issues due to network dependency
- Scalability problems for large-scale or real-time analysis

In response to these challenges, ISRO (Indian Space Research Organisation) raised a real-world problem: to find a solution that can perform real-time semantic segmentation on WMS images without server-side dependence, enabling efficient planning and monitoring directly from satellite imagery.

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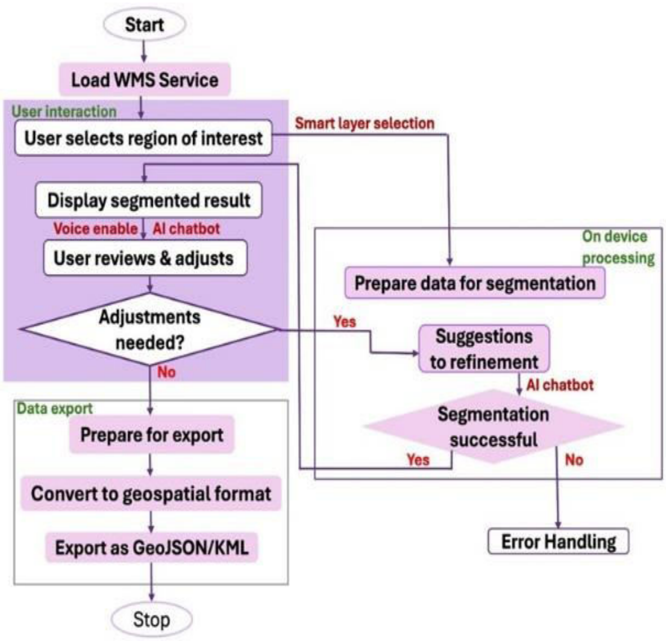
IV. SOLUTION APPROACH



V. METHODOLOGY

The development of the proposed system involves several key phases, ranging from data acquisition to real-time semantic segmentation and geospatial data export. The focus is on maximizing on-device GPU/NPU utilization for efficient, real-time processing while maintaining user accessibility and WMS compatibility.

1. Data Acquisition via Web Map Service (WMS)

Utilize OGC-compliant WMS services to load satellite imagery dynamically.
Integrate the WMS data into a desktop (QGIS plugin), mobile, or web-based interface for further processing.
Allow users to select regions of interest (ROI) interactively for segmentation.

2. Preprocessing of Satellite Images

Perform image normalization, resizing, and format conversion suitable for segmentation models.
Apply tiling mechanisms if the image is large, ensuring efficient memory use.
Optimize image loading to maintain smooth user experience.

3. On-Device Semantic Segmentation

Deploy lightweight, pre-trained deep learning models (e.g., MobileNet, U-Net Lite) optimized for GPU/NPU acceleration.
Utilize technologies like:
TensorFlow Lite / ONNX Runtime for mobile/desktop GPU/NPU inference.
WebGL/Web GPU for browser-based GPU acceleration.
Run real-time inference on the loaded satellite images, generating pixel-level classified maps.

4. User Interaction and Controls

Develop an intuitive user interface using frameworks like ReactJS (for web), or native interfaces for mobile and desktop.
Enable multimodal interaction:
Voice commands using Speech Recognition APIs (e.g., Google Cloud Speech-to-Text)
Touch/Mouse-based segmentation refinement tools
Text-based commands for feature selection or region identification

5. **Post-Segmentation Processing**

Display segmentation output using color-coded overlays for various classes (e.g., buildings, trees, water bodies).
Provide tools to manually refine or correct segmentation results through bounding boxes or brush tools.

6. Geospatial Data Export

Convert the selected and segmented areas into geospatial formats like Geo JSON or KML.
Allow download or sharing of geospatial data for integration into GIS platforms.

7. Crowd-sourced Data Portal (Optional Feature)

Enable users to upload local imagery or changes (e.g., new construction) to a centralized map update portal.
Implement AI-based validation mechanisms to verify accuracy and consistency of crowd-sourced data.

8. **Performance Optimization**

Implement incremental learning where the model updates with user corrections in small batches to improve accuracy over time.
Continuously monitor GPU/NPU resource usage to ensure smooth operation on different devices.
Conduct benchmarking tests to compare CPU vs GPU/NPU performance on various devices.

VI. OBJECTIVES

1. Develop a User-Friendly Interface

Design an intuitive application interface (mobile, desktop, or web-based) that is accessible to both technical and non-technical users.
Incorporate voice-assisted controls to allow users to operate and refine segmentation using voice commands.

2. Enable On-Device Semantic Segmentation

Implement real-time semantic segmentation using on-device GPU/NPU acceleration to enhance performance and responsiveness.
Eliminate the need for server-side GPU computation, thereby reducing network latency and operational costs.

3. Optimize System Performance

Ensure the system is capable of fast processing speeds and low resource consumption by optimizing the deep learning models for mobile and desktop GPUs/NPUs.
Support offline functionality, allowing segmentation even without an active internet connection.

4. Integrate WMS (Web Map Service) Compatibility

Ensure full OGC-compliant WMS support, enabling the application to dynamically load satellite imagery from various geospatial data providers.

5. Provide Geospatial Data Export

Allow users to export segmented data in widely used geospatial formats such as Geo JSON and KML, enabling easy integration with GIS platforms like QGIS and ArcGIS.

6. Facilitate Crowd-Sourced Data Contributions

Develop a portal for users to upload images or report geographic changes (e.g., new buildings or roads) to assist in crowd-sourced map updates.
Incorporate AI-based validation mechanisms to ensure the accuracy and reliability of user-contributed data.

7. Maintain Data Privacy and Security

Guarantee that all processing occurs locally on the user's device to ensure data privacy and security, especially for sensitive applications like government planning or defense monitoring.

VII. CONCLUSION

The proposed system addresses a critical challenge in the field of geospatial analysis and remote sensing by enabling real-time, on-device semantic segmentation of satellite imagery obtained via Web Map Services (WMS)\. By leveraging the computational power of on-device GPUs and NPUs, this tool minimizes dependence on server-side processing, thereby reducing latency, improving responsiveness, and enhancing data privacy.

The application is designed to be user-friendly, with support for voice commands, touch inputs, and text-based interactions, making it accessible to both technical and non-technical users. Its ability to export geospatial data in formats such as Geo JSON and KML ensures seamless integration with existing GIS platforms, aiding in tasks such as infrastructure planning, environmental monitoring.

VIII. FUTURE SCOPE

Incremental Learning : Use an incremental learning approachwhere the system updates the segmentation model with user corrections in smaller batches, reducing the computational burden.

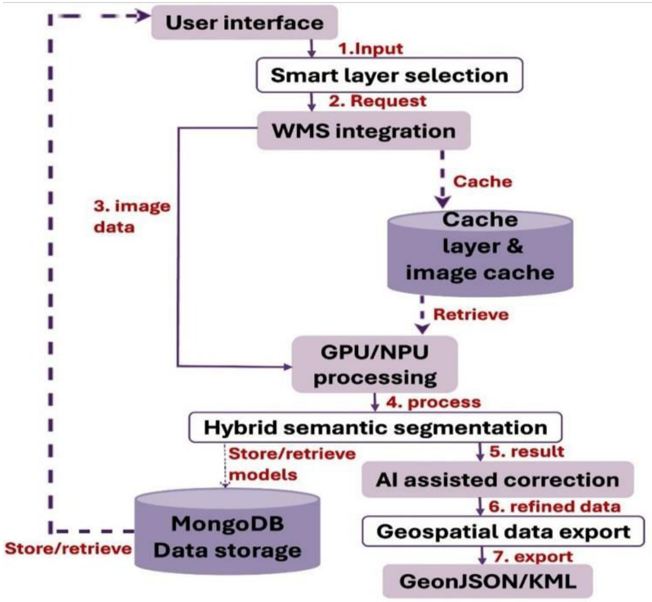
Voice Recognition API: Use a reliable speech engine like Google
Cloud's Speech Text API, which supports domain specific language models.

Develop a Comprehensive API: Create a robust API that allow third party developers to integrate this semantic segmentation functionality into their own applications. Implement Augmented Reality (AR) RealTime Collaborative Segmentation: Enable multiple users to work on the same map or image in real time, where changes made by one user are instantly reflected for others.

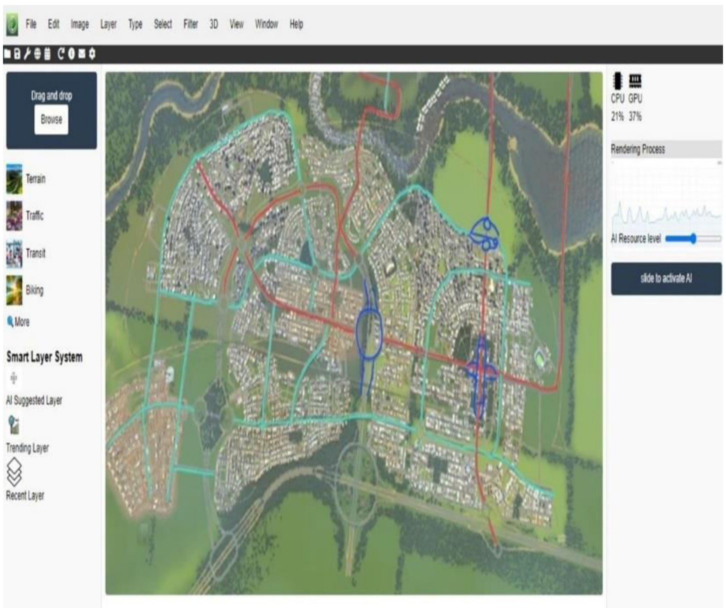
IX. CHALLENGES

[1]Hardware Limitations and Compatibility
[2]Optimization of Deep Learning Models
[3]Real-Time Processing and Responsiveness
[4]WMS Data Integration and Standardization
[5]Crowd-Sourced Data Reliability

X. DATA FLOW DAIGRAM



XI. PROTOTYPE IMAGE



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