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INSTITUTE OF ENGINEERING

KATHMANDU ENGINEERING COLLEGE

KALIMATI, KATHMANDU

Major Project Proposal Report on

GARUD-UAV: A Deep Learning Approach to Image Upscaling for Land Use Classification

BY

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Abstract

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List of Abbreviation

AI Artificial Intelligence

GPIO General Purpose Input Output

IoT Internet of Things

ML Machine Learning

RAM Random Access Memory

OS Operating System

BRNN Bidirectional Recurrent Neural Networks

GRU Gated Recurrent Units

MIMO Multiple Input Multiple Output

SoC System-on-Chip

USB Universal Serial Bus

Wi-Fi Wireless Fidelity

NLP Natural Language Processing

TTS Text-To-Speech

API Application Programming Interface

ARM Advanced RISC Machine

RISC Reduced Instruction Set Computer

IP Internet Protocol

MCU Micro-Controller Unit

Chapter 1: Introduction

1.1 Background Theory

The rapid advancement of Unmanned Aerial Vehicles (UAVs) has transformed applications in environmental monitoring, agriculture, and urban planning by providing cost-effective and high-resolution data collection capabilities [1], [2]. Fixed-wing UAVs, in particular, offer significant advantages for land use image classification due to their extended range, longer endurance, and ability to cover large areas efficiently, making them ideal for wide-areas surveillance and mapping tasks [2]. These vehicles can capture high-resolution aerial imagery, enabling precise analysis of land use patterns critical for precision agriculture, urban development, and disaster management [1], [4]. However, challenges such as limited payload capacity, regulatory constraints, and the need for advanced image processing to achieve high-quality outputs persist, necessitating innovative design and algorithmic solutions [1], [2].

A key component of this project is the integration of Enhanced Super-Resolution Generative Adversarial Network (ESRGAN), a state-of-the-art deep learning model for single image super-resolution (SISR) introduced by Wang et al. in 2018 [5]. ESRGAN employs a Generative Adversarial Network (GAN) framework, comprising a generator that creates high-resolution images from low-resolution inputs and a discriminator that ensures realism. Noted for its ability to reconstruct realistic textures and fine details, ESRGAN is ideal for enhancing images captured by UAV-mounted cameras, such as those using Raspberry Pi modules, typically upscaling images by a factor of 4x [5]. This capability is particularly valuable for land use classification, where high-resolution imagery is essential for identifying intricate land features.

This research project aims to design and develop a fixed-wing UAV tailored for land use image classification, leveraging lightweight materials, advanced sensors, and ESRGAN for enhanced image processing to improve data accuracy and operational efficiency. By addressing design considerations such as aerodynamic efficiency, flight stability, and integration of high-resolution imaging systems, this project seeks to create a UAV capable of collecting and processing aerial imagery for accurate land use analysis [2]. Drawing on prior research, including deep learning applications for UAV systems and their use in precision agriculture [1], [4], this project will optimize UAV performance for environmental monitoring tasks. The outcome is expected to contribute to UAV-based remote sensing, offering a scalable solution for land use analysis in diverse geographical contexts.

1.2 Problem Statement

Land use and land cover (LULC) classification is critical for effective environmental management, agricultural monitoring, urban planning, and disaster response. Traditionally, satellite imagery has been the primary source for such analysis; however, limitations such as low spatial resolution, infrequent data updates, atmospheric disturbances, and high operational costs restrict its applicability for high-precision, real-time monitoring [1]. In contrast, UAVs offer a flexible, cost-effective, and scalable solution for high-resolution remote sensing. Among UAV types, fixed-wing aircraft present superior advantages for surveying large geographical areas due to their extended flight duration, aerodynamic efficiency, and higher operational altitudes [2].

Despite their potential, existing UAV platforms used for LULC classification are often either commercially expensive, overly complex for academic research and field adaptation, or designed around rotary-wing systems that lack the range and endurance needed for broad-area coverage [3]. Moreover, there is a lack of integrated, low-cost fixed-wing UAV solutions that combine autonomous navigation, high-resolution image acquisition, and onboard or post-processed land classification capability tailored to specific regional or environmental needs.

Therefore, there exists a critical need to develop a custom-built, fixed-wing UAV system optimized for land use image classification—one that is affordable, reliable, and capable of autonomous operation in varied field conditions. This research project addresses that need by designing and implementing a fixed-wing UAV equipped with geo-referenced imaging systems and an image-processing pipeline to enable accurate and efficient land use classification.

Chapter 2: Literature Review

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Chapter 3: Related Theory

3.1 Hardware

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Figure 3.1: Raspberry Pi 4 Model B

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3.2 Software Overview

3.2.1 ESRGAN for Image Super-Resolution

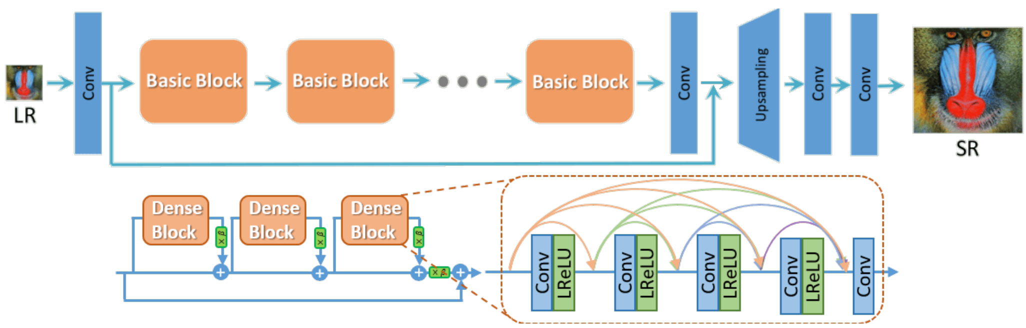

Figure 3.2: ESRGAN Architecture with Residual-in-Residual Dense Blocks (RRDB)

ESRGAN introduced by Wang *et al.* in 2018 [1], improves upon SRGAN by employing a deep generator built from Residual-in-Residual Dense Blocks (RRDB) without batch normalization. Each RRDB combines multiple convolutional layers, local dense connections, and global residual links to capture complex image features. The generator upsamples low-resolution inputs (e.g. 820×616 pixels) by a factor of 4× to high-resolution outputs (e.g. 3280×2464 pixels). The discriminator is relativistic, estimating the probability that a real image is more realistic than a generated one, which enhances stability and visual fidelity. ESRGAN further integrates a perceptual loss based on high-level VGG features computed before ReLU activations, preserving fine textures and brightness consistency. This design enables ESRGAN to produce photorealistic details, as demonstrated by its victory in the PIRM2018 SR Challenge [1].

In our UAV system, images captured onboard with a Raspberry Pi USB Camera are retrieved post-flight. ESRGAN runs on a ground PC to upscale extracted frames, recovering critical details (e.g. building outlines, vegetation patterns) necessary for accurate land use classification in the Kathmandu region.

3.2.2 Comparison of Super-Resolution Models

We compare ESRGAN with earlier SR approaches:

Model	Year	Architecture	Strengths	Weaknesses
SRCNN	2014	3-layer CNN	Simple, fast	Overly smooth outputs [2]
FSRCNN	2016	CNN + deconv	Efficient, higher PSNR [2]	Limited texture detail
EDSR	2017	Deep ResNet	High PSNR, faster [3]	Less perceptual quality
ESRGAN	2018	GAN + RRDB	Realistic textures, sharp edges [1]	Computationally intensive

Table 3.1: Comparison of Super-Resolution Models

3.2.3 Land Use Classification

Land use classification from UAV imagery entails categorizing pixels or patches into classes such as forest, agriculture, water, and urban. Common approaches include:

- **Convolutional Neural Networks (CNNs)**: End-to-end models (e.g. U-Net, ResNet, EfficientNet) that learn spatial hierarchies directly from upscaled images [4].
- **Random Forest (RF)**: Ensemble of decision trees trained on raw pixels or derived indices, robust to overfitting and effective for moderate datasets [2,4].
- **Support Vector Machine (SVM)**: Kernel-based classifier suitable for moderate-sized, well-separated classes [2,4].

A hybrid approach often combines CNN feature extractors with RF or SVM classifiers, leveraging deep networks for hierarchical feature learning and traditional ML for robust classification when labeled data is limited.

3.2.4 Software

The software pipeline integrates the following tools and libraries:

- **OpenCV**: For image/frame extraction, filtering, and geometric transformations [5].
- **NumPy & SciPy**: Core numerical and array operations for preprocessing.
- **scikit-learn**: Implements RF and SVM classifiers, data splitting, scaling, and evaluation utilities [6].
- **TensorFlow & PyTorch**: Deep learning frameworks for ESRGAN and CNN implementation. PyTorch (BasicSR toolkit) eases experimentation [7], while TensorFlow (TF-Hub ESRGAN) supports scalable deployment [8].
- **GDAL/Rasterio**: For handling geo-referenced imagery and aligning with regional GIS data [9].

3.2.5 Dataset

1. Kathmandu Land Use Datasets

Region-specific datasets used for land use classification in Kathmandu:

- **Nepal National Land Cover Dataset**: Annual land-cover maps (2000–2022) from Landsat imagery via Google Earth Engine, covering forests, agriculture, water, and built-up areas[10].
- **Kathmandu City Land Use Shapefiles**: Urban land use polygons (residential, commercial, parks) for Kathmandu Metropolitan City (2011) from ICIMOD[11].
- **OpenStreetMap Polygons**: Land-use tags for Kathmandu accessible through the Humanitarian Data Exchange[12].

2. Image Super-Resolution Datasets

Datasets used to train and evaluate ESRGAN and other super-resolution models:

- **DIV2K**: A large-scale dataset designed for image super-resolution, consisting of 1000 high-resolution images and their corresponding low-resolution counterparts. Suitable for training deep SR models.
- **Set5 and Set14**: Benchmark datasets commonly used for evaluating the performance of super-resolution models. While smaller in size, they are widely adopted for quantitative comparisons.

These datasets provide essential ground truth for training and validating both our land use classification pipeline and image super-resolution models.

Chapter 4: Feasibility Study

4.1 Technical Feasibility

4.1.1 Hardware Availability and Requirements

- **UAV Hardware:** Raspberry Pi 4 with a camera module for capturing aerial imagery.
- **ESRGAN Processing:** Ground PC with GPU or cloud-based services (e.g., Google Colab) for super-resolution.
- **Flight Components:** Motors, ESCs, batteries, and flight controllers, readily available in local electronics stores in Kathmandu.

4.1.2 Software Tools and Implementation

- **ESRGAN Super-Resolution:** Implemented using PyTorch or TensorFlow with open-source pretrained models.
- **Land Use Classification:** Utilizes scikit-learn (SVM, RF) and CNNs using PyTorch or TensorFlow.
- **Image Processing:** Managed with OpenCV, NumPy, and GDAL/Rasterio for geospatial tasks.

4.1.3 UAV Design and Development Tools

- **Design:** AeroToolbox and similar open-source tools for wing loading, CG calculation, and thrust analysis.
- **Build Materials:** Depron sheets used for lightweight UAV frame construction, available locally.

4.1.4 Time Feasibility

- **Design, Assembly, and Software Development:** UAV frame design, hardware integration, and implementation of the image processing/classification pipeline will take around 3 months.

- **Testing and Validation:** Field testing of UAV and validation of outputs will require 2–3 weeks.
- **Data Collection and Model Training:** Capturing aerial imagery, labeling datasets, and training/testing models with ESRGAN-upscaled images will take 2.5–3.5 months.

Total Estimated Time: Approximately 6–7 months.

4.2 Economic Feasibility

- **Cost-Effective Setup:** Low-cost components like Raspberry Pi, camera modules, depron, and UAV parts are affordable and readily available in Kathmandu (e.g., local stores or Daraz).
- **Free Software and Compute Resources:** Software tools such as PyTorch, TensorFlow, OpenCV, and cloud services like Google Colab are free, minimizing development cost.

Market Potential and Conclusion: This project provides a scalable, low-cost solution for high-resolution land-use classification using UAV imagery and super-resolution techniques. Its modular structure and reliance on open-source software and affordable components make it both technically and economically viable. With applications in urban planning, smart agriculture, and environmental monitoring, the system shows strong commercialization potential. Future upgrades like onboard inference, real-time telemetry, and satellite data integration can further enhance its market value.

Chapter 5: Methodology

5.1 System Block Diagram

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5.2 Flow Chart

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Chapter 6: Result And Analysis

6.1 Expected Output

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Gantt Chart

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Cost Estimation

Electronics & Core Components

Item	Quantity	Cost (NRs)
FLYSKY Receiver	1	8000
30A ESC Skywalker	1	2000
Flight Stabilizer (NXE4 EVO)	1	4500
1000KV Brushless Motor	1	800
MG996 Metal Gear Servo	4	3040
2200mAh 3S LiPo Battery	1	3150
Buck Module Voltage Regulator	1	550
Raspberry Pi 4B with USB Camera and HDMI Cable	1	0
Total		**22040**

Table 6.1: Electronics and Core Components for Fixed-Wing UAV

Frame & Construction Materials

Item	Quantity	Cost (NRs)
Depron Sheet(1000*600 mm)	4	10 000
Aluminum Motor Mount (L-shape)	1	150
Push Rod (1m)	2	400
Total		**10550**

Table 6.2: Frame and Construction Materials for Fixed-Wing UAV

Miscellaneous Accessories

Item	Quantity	Cost (NRs)
Hot Glue Gun Stick	10	200
Duct/Binding Tape	3 rolls	300
XT60 Connector Pair	2	500
3-Pin Orange Connector Pair	4	60
Servo Wire Cable (5m)	1	75
Propeller (7x5 inch)	4	300
Bullet Propeller Holder Adapter	1	170
Jumper Wire (MM, MF, FF, each 5)	15	30
Total		**1635**

Table 6.3: Miscellaneous Accessories for Fixed-Wing UAV

Grand Total

Category	Cost (NRs)
Electronics and Core Components	22 040
Frame and Construction Materials	10 550
Miscellaneous Accessories	1635
Grand Total	**34225**

Table 6.4: Grand Total Cost for Fixed-Wing UAV

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