AN EXPERIENTIAL LEARNING TASK REPORT ON

Wildfire Detection Using Satellite Image Processing by Hyperspectral Image Analysis

BACHELOR OF TECHNOLOGY

IN

Artificial Intelligence and Machine Learning

SUBMITTED BY

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LIST OF ABBREVIATIONS

Sr. No.	Abbreviated Word	Expansion
1.	GUI	Graphical User Interface
2.	CNN	Convolutional Neural Network
3.	RGB	Red Green Blue
4.	SVM	Support Vector Machine
5.	SKLearn	SciKit Learn (Python Machine Learning Library)
6.	ESA	European Space Agency
7.	NASA	National Aeronautics and Space Agency

CHAPTER I: INTRODUCTION

1.1. Digital Image Processing Domain:

Satellite Image Processing for Disaster Management

Fig. 1.1. Satellite Image of Forest Fire [1]

1.2. Motivation:

The motivation behind the project of wildfire detection from satellite image data is to leverage technology and data-driven approaches to improve wildfire management, protect ecosystems and biodiversity, safeguard public health and safety, and address the challenges posed by climate change.

a. Environmental Monitoring and Conservation

- Wildfires have significant environmental impacts, including habitat destruction, loss of biodiversity, and degradation of ecosystems.
- Monitoring wildfires using satellite imagery allows researchers and conservationists to assess the extent and severity of fire damage, track changes in vegetation cover, and evaluate the long-term ecological consequences.

b. Public Health and Safety

- Wildfires produce smoke, ash, and other pollutants that can pose health risks to nearby communities, particularly those with respiratory conditions.
- By detecting wildfires early and accurately, authorities can issue warnings and advisories to affected populations, advising them to take precautions such as staying indoors, wearing masks, and avoiding outdoor activities.

c. Early Warning and Response
- Early detection of wildfires is crucial for timely response and mitigation efforts. By analysing satellite imagery, it’s possible to detect wildfires at their early stages before they escalate into large, destructive fires.
- This early warning can help authorities and emergency responders deploy resources more effectively to contain and extinguish the fires, potentially saving lives and minimizing property damage.

d. Resource Allocation and Management
- Wildfires require substantial resources to combat, including firefighting personnel, equipment, and aircraft.
- By monitoring wildfires from space, authorities can better allocate resources based on the location, size, and intensity of fires.
- This optimizes resource deployment, improves coordination among agencies, and enhances the overall efficiency of wildfire response operations.

e. Climate Change and Resilience:
- Climate change is heightening wildfire risks by increasing temperatures, altering precipitation patterns, and creating drier conditions conducive to fire spread.
- Monitoring wildfires using satellite imagery provides valuable data for studying the relationship between climate change and wildfire activity, identifying trends and patterns over time, and developing strategies to build resilience and adapt to changing environmental conditions.

By detecting and monitoring wildfires more effectively, it is possible to mitigate their impacts and work towards building more resilient and sustainable communities.

1.3. Objectives:

The objectives wildfire detection using satellite image data, include improving wildfire management, enhancing public safety, and minimizing environmental impacts.

Some specific objectives of the project are as follows:

a. Early Detection**:**

- The objective is to identify smoke plumes, heat signatures, or other indicators of fire activity as soon as possible to enable prompt response and containment efforts.

- For this, we develop algorithms and techniques to detect wildfires at their early stages using satellite imagery.

b. Accurate Identification**:**

- We aim to improve the accuracy and reliability of wildfire detection by distinguishing between actual fire events and false alarms or non-fire phenomena (e.g., clouds, shadows).
- The objective is to minimize false positives and negatives to ensure that resources are allocated efficiently and effectively.

c. Spatial Mapping:

- It is possible to create detailed maps of wildfire extent, boundaries, and progression using satellite imagery.

- The objective is to provide accurate spatial information to emergency responders, land managers, and decision-makers for planning and operational purposes.

d. Severity Assessment:

- It is possible to estimate the severity and intensity of wildfires based on satellite observations, including factors such as fire size, temperature, rate of spread, and fuel consumption.

- The objective is to assess the potential impacts of wildfires on ecosystems, infrastructure, and communities and prioritize response efforts accordingly.

e. Smoke Monitoring:

- The project can be extended to monitor smoke plumes and air quality impacts resulting from wildfires using satellite data.

- The objective is to track the dispersion of smoke, assess its health effects on nearby populations, and issue timely warnings and advisories to minimize exposure risks.

1.4. Project Scope and Importance

1.4.1. Scope of the Project:

- Project Introduction
- Data Collection and Preparation
- Image Processing and Analysis
- Feature Extraction
- Model Development
- Real-time Monitoring
- Integration with GUI
- Alerting and Notification System

- Accuracy Assessment and Validation
- Scalability and Cloud Deployment
- Ethical and Environmental Considerations
- Documentation and Reporting
- Future Enhancements

1.4.2. Importance of the Project:

The project of wildfire detection from satellite image data holds significant importance due to its potential impact on various aspects of society, the environment, and public safety.

Some of the reasons for which the project is important, are as follows:

a. Resource Allocation and Management:
   - Wildfire response requires substantial resources, including firefighting personnel, equipment, and logistical support.
   - Satellite-based wildfire detection helps optimize resource allocation by providing real-time information on fire location, size, and behaviour, enabling authorities to deploy resources more effectively and efficiently.

b. Data-Driven Decision Making:
   - Satellite-based wildfire detection provides stakeholders with valuable data and insights for evidence-based decision-making in wildfire management and emergency response.
   - By integrating satellite imagery with geographic information systems (GIS) and decision support systems (DSS), authorities can make informed decisions, coordinate response efforts, and prioritize interventions to effectively combat wildfires and protect communities.

c. Cross-Sector Collaboration:
   - Wildfire detection projects involving satellite imagery foster collaboration and coordination among government agencies, research institutions, non-profit organizations, and private sector entities.
   - By sharing data, expertise, and resources, stakeholders can leverage collective capabilities and address wildfire challenges more comprehensively and collaboratively.

d. Public Awareness and Education:
   - Wildfire detection projects raise public awareness about wildfire risks, prevention strategies, and emergency preparedness measures.
   - By educating individuals and communities about wildfire hazards and empowering them to take proactive measures, these projects contribute to building community resilience and fostering a culture of wildfire safety.

1.5. Feasibility

The feasibility of the project and its deployment, depend on the following factors:

a. Technological Feasibility
- Satellite Technology: Modern satellites equipped with optical, thermal, and infrared sensors provide detailed imagery that can be used to detect and monitor fire activity over large areas.
- Remote-Sensing Techniques: Techniques such as image processing, machine learning, and data analytics enable the extraction of valuable information from satellite imagery for wildfire detection, classification, and mapping.

b. Data Availability and Accessibility
- Satellite Data Sources: Satellite imagery from public and private sources, such as NASA, ESA, and commercial satellite providers, is readily available for wildfire monitoring purposes. These data sources offer a wealth of information that can be leveraged for wildfire detection and analysis.
- Open Data Sources: Open data platforms and repositories facilitate access to satellite imagery, geospatial data, and related resources for researchers, developers, and stakeholders interested in wildfire detection projects.

c. Operational Considerations
- Integration with Existing Systems: Integrating wildfire detection capabilities with existing emergency management systems, decision support tools, and communication networks enhances the project's operational effectiveness and relevance.
- Inter-agency Collaboration: Collaboration with government agencies, emergency responders, and other stakeholders is critical for successful integration and deployment.
- Scalability and Sustainability: Designing the project with scalability and sustainability in mind ensures that it can adapt to changing needs, scale to larger geographic areas, and continue operations over the long term.

d. Regulatory and Ethical Considerations
- Data Privacy and Security: Compliance with data privacy regulations and best practices for handling sensitive information is essential to protect individuals' privacy rights and ensure data security.
- Ethical Use of Data: Ensuring the ethical use of satellite imagery and data involves considerations of fairness, transparency, and accountability in decision-making processes, particularly regarding the dissemination of information and potential impacts on affected communities.

1.6. Constraints

The following constraints may affect the execution and outcomes of the project:

a. Data Availability and Quality

- Limited Access to Satellite Data: Access to high-quality satellite imagery may be restricted or costly, particularly for high-resolution or real-time data.
- Data Latency: Delays in obtaining satellite imagery, processing, and dissemination can hinder timely detection and response to wildfires, especially during critical fire events.
- Data Quality and Consistency: Variability in data quality, sensor characteristics, and atmospheric conditions can affect the reliability and consistency of wildfire detection algorithms and analysis results.

b. Technological Limitations
- Computational Resources: Processing large volumes of satellite imagery and conducting complex data analytics require substantial computational resources, including high-performance computing infrastructure and storage capacity.
- Algorithm Complexity: Developing and implementing advanced algorithms for wildfire detection, image processing, and machine learning may require specialized expertise and computational resources, limiting scalability and applicability.
- Sensor Limitations: Satellite sensors may have limitations in terms of spatial resolution, spectral bands, temporal coverage, and cloud cover, impacting the ability to detect and monitor wildfires accurately.

c. Financial and Resource Constraints

- Funding Availability: Securing adequate funding to support the project's objectives, including satellite data acquisition, infrastructure development, personnel costs, and ongoing operations, can be challenging.
- Cost of Satellite Data: Acquiring commercial satellite imagery or subscribing to satellite data services can incur significant costs, especially for high-resolution or real-time data, which may be prohibitive for some organizations or regions.

d. Logistic Challenges

- Geographic Coverage: Satellite imagery may not cover all regions or terrains uniformly, limiting the geographic coverage and applicability of wildfire detection systems, particularly in remote or inaccessible areas.
- Ground Truth Validation: Verifying satellite-based wildfire detections with ground truth data, such as field observations or ground-based sensors, can be logistically challenging and resource-intensive, especially in rugged or hazardous environments.

e. Regulatory and Policy Constraints

- Data Sharing and Licensing: Compliance with data sharing agreements, licensing requirements, and intellectual property rights associated with satellite imagery may restrict the use and distribution of data for wildfire detection projects.
- Privacy and Security Regulations: Ensuring compliance with data privacy regulations and ethical guidelines when collecting, storing, and processing satellite imagery, particularly for sensitive or personally identifiable information, is essential to protect individual privacy rights and data security.

CHAPTER II: LITERATURE SURVEY

Authors	Method	Database	Results
Short, Karen C.	Spatial Wildfire Occurrence Data for the United States, 1992-2015: Used Local Binary Pattern and Wavelet Decomposition for Fire Detection [2].	https://www.fs.usda.Gov/rds/archive/catalog/RDS-2013-0009.4	The resulting product, referred to as the Fire Program Analysis fire-occurrence database (FPA FOD), includes 1.88 million geo-referenced wildfire records, representing a total of 140 million acres burned during the 24-year period [2].
Wang, M., Jiang, L., Yue, P., Yu, D., and Tuo, T	Use of two -class SVM classifier and Deep Learning methods driven by in situ video and remote-sensing images [3].	https://essd.copernicus.org/preprints/essd-2022-394/	The resulting project constructs a 100,000-level Flame and Smoke Detection Dataset (FASDD) based on multi-source heterogeneous flame and smoke images [3].
Thangavel K, Spiller D, Sabatini R, Amici S, Sasidharan ST, Fayek H, Marzocca P	Autonomous Satellite Wildfire Detection Using Hyperspectral Imagery and Neural Networks: A Case Study on Australian Wildfire [4].	https://doi.org/10.3390/rs15030720	The resulting project used SVM and Neural Networks to achieve a final overall accuracy of 97.83 percent for the model [4].
Lalitha, K., Veerapandu, G.	Forest Fire Detection Using Satellite Images [5].	https://doi.org/10.1007/978-981-19-0108-9_29	The resulting project accurately locates the hot spot areas for determining the forest fire's locations, using spatial high-resolution imagery [5].
N. T. Toan, P. Thanh Cong, N. Q. Viet Hung and J. Jo	A deep learning approach for early wildfire detection from hyperspectral satellite images [6].	https://ieeexplore.ieee.org/document/8932740	The resulting project is 1.5 times faster detections compared to the benchmark. Robust against different types of wildfires and adversarial conditions, it showed an F1-score of 94% [6].

Table 2.1

CHAPTER III: METHODOLOGY OF IMPLEMENTATION

3.1. Workflow Diagram

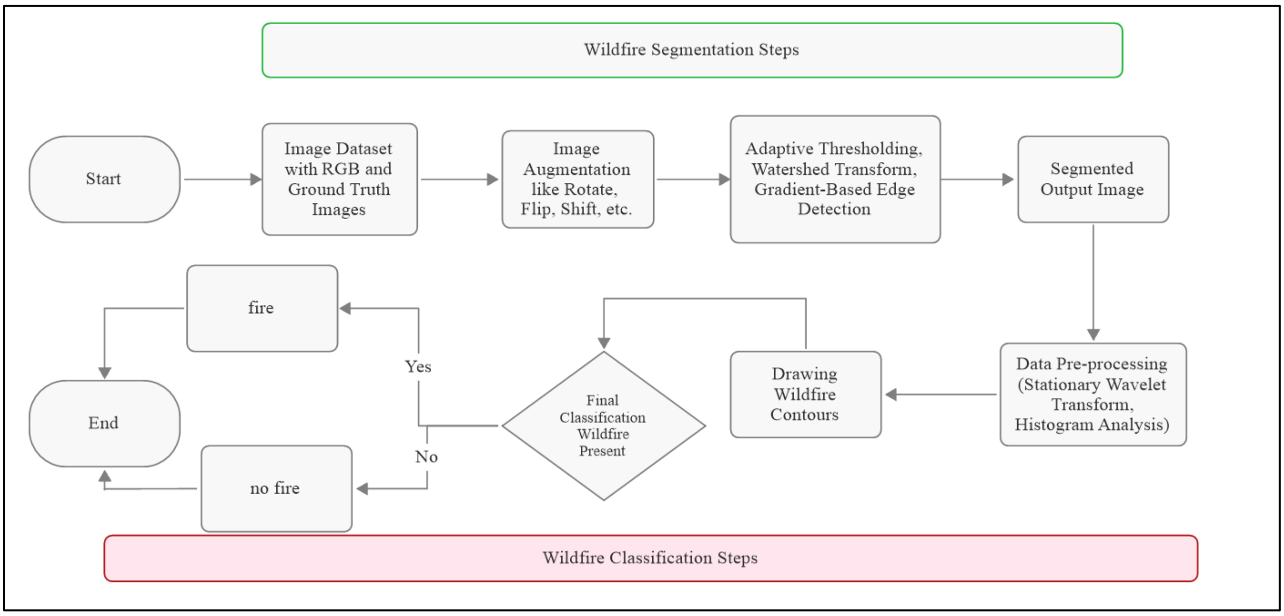

Fig. 3.1.: Block Diagram

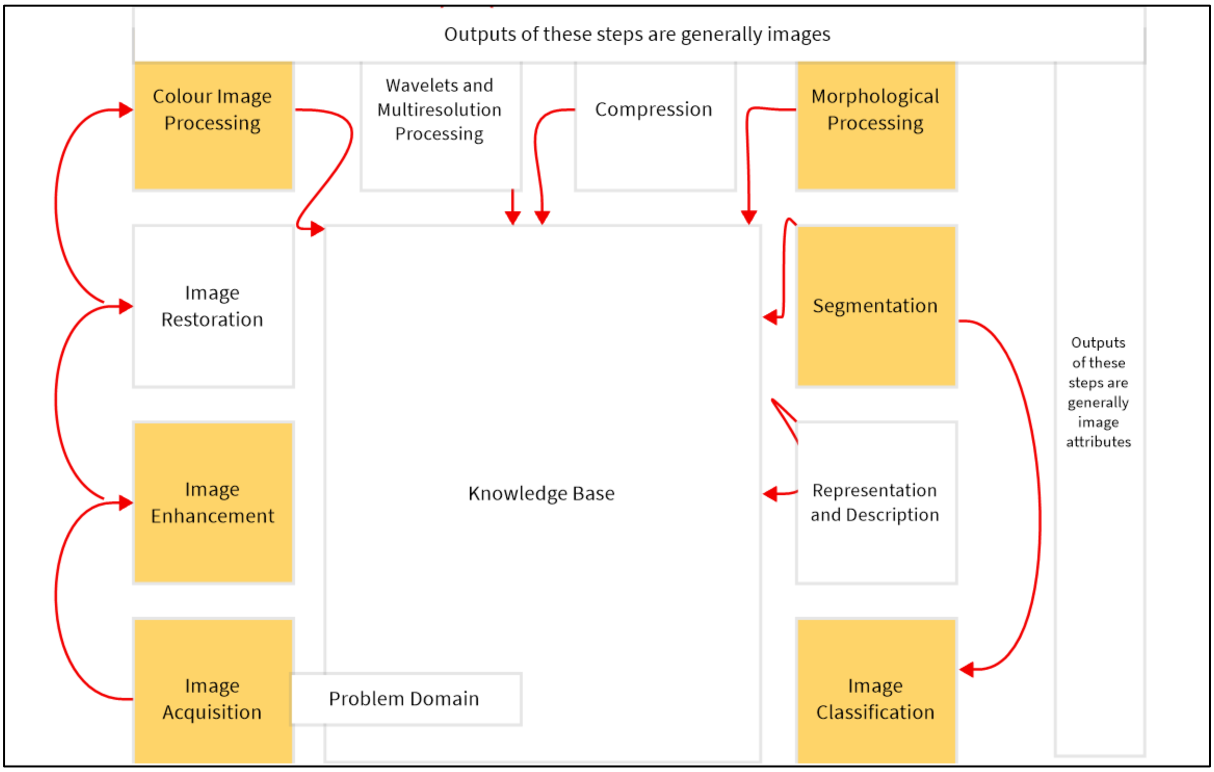

Fig 3.2.: Digital Image Processing Steps

3.2. Digital Image Processing Steps

1. Image Acquisition:
   Satellite images will be obtained from accessible satellite systems.

2. Image Enhancement:

   - Histogram Equalization, Contrast Stretching and Spatial Filtering Techniques such as Median Filtering and Gaussian Smoothing, improve image contrast, reduce noise, and enhance image clarity.
   - This helps improve the visibility of relevant features like smoke plumes, fire fronts, and burned areas, making it easier for analysts to identify and interpret them.
   - Satellite Image Enhancement can aid in distinguishing between different land cover types, highlighting areas of active fire, and improving the visualization of smoke plumes.

3. Colour Image Processing:

   - Colour space transformations can convert images between different colour spaces such as RGB or HSV, to manipulate specific colour channels or components.
   - Further, colour-based segmentation techniques can be used to separate regions of interest based on their colour characteristics.
   - Colour information in satellite images can provide valuable insights into wildfire-related features, such as fire intensity, smoke colour, and vegetation health.
   - Analysing colour information in satellite images can help differentiate between fire-affected areas, healthy vegetation, and other land cover types, aiding in wildfire detection and monitoring.

4. Morphological Processing:

   - Morphological processing can help clean up segmentation results, remove small artifacts, and refine the boundaries of fire-affected areas, smoke plumes, and other features of interest.
   - Morphological operations are used to analyse and manipulate the shape and structure of objects in images. These can then be useful for extracting and refining features related to wildfires.
   - Techniques include Erosion and Dilation to modify the shape and size of objects by adding and removing pixels respectively, as well as Opening and Closing to remove noise, fill gaps, or separate overlapping objects, by combining erosion and dilation in succession.

5. Segmentation:

- Segmentation helps isolate fire-affected areas, smoke plumes, burned vegetation, and other features from the background, enabling further analysis and classification.
- It divides an image into meaningful regions or objects, facilitating the identification and analysis of specific features relevant to wildfire detection.
- Segmentation Techniques include Thresholding, Clustering, Edge Detection and Region Growing. These techniques help to separate pixels or regions on their colour, intensity, or other characteristic values.

6. Object Classification:

- Classification assigns labels or categories to image pixels or regions based on their spectral, spatial, or contextual properties, enabling the identification and mapping of wildfire-related features.
- It helps distinguish between different land cover types, detect changes in vegetation health, identify fire hotspots, and map the extent and severity of wildfires in satellite images.
- For classification tasks, labelled training data is most commonly used, as in the Supervised Learning approach; however, clustering based on the spectral or spatial properties of the pixels is also feasible, as in the Unsupervised Learning approach.

3.3. Execution of the Project

1. The project will be executed on a Python IDE such as Jupyter Notebook or PyCharm.
2. The necessary Python Image Processing and Machine Learning libraries such as OpenCV, Pandas, Matplotlib and SKLearn will be imported.
3. The necessary image datasets will be pre-processed, and then loaded into a Pandas DataFrame for model training, validation and deployment.
4. The performance of the classification model will be tested with the help of Performance Metrics.

3.4. Preprocessing and Feature Extraction Techniques

Feature Extraction is used for Texture, Colour, Vegetation and Thermal Analysis of image data, among others.

Colour Segmentation utilizes different colour spaces (e.g., RGB, HSV) and segmentation techniques to isolate regions with distinct colour signatures associated with fire, smoke, and vegetation. It is used to identify colour signatures associated with fire and smoke. For example, smoke tends to be whitish or greyish, while fire may exhibit various shades of red, orange, or yellow.

Contour Detection identifies contours or outlines of objects in the image using techniques like edge detection or region growing.

Local Binary Patterns (LBP) is used to describe local texture patterns by comparing the intensity of a central pixel with its neighbouring pixels, producing a histogram of binary patterns.

Vegetation Indices like NDVI (Normalized Difference Vegetation Index) or NBR (Normalized Burn Ratio) are used to assess vegetation vigour or fire severity, as wildfires often result in vegetation damage or destruction.

Thermal Analysis makes use of thermal infrared bands to detect hotspots associated with active fires. Thermal anomalies above a certain temperature threshold can be indicative of fire activity.

3.5. Final Expected Result

The final expected result of the project is to develop a model that can classify any given satellite image as ‘fire’ or ‘no fire’ accurately. This is done through digital image processing of satellite image data, which is subsequently used to train a classification model such as CNN (Deep Learning), Naïve Bayes, SVM or Decision Tree.

The performance metrics of the classification model, such as accuracy, precision, recall and F1-Score, are indicators of how well the model has performed on training, validation and test datasets.

CHAPTER IV: RESOURCES

4.1. Hardware and Software Tools

Hardware: Intel i5, GPU: Iris, Windows 11, 16 GB DDR5 RAM

Software: Google Collaboratory, VS Code

Libraries: Matplotlib, Pandas, Seaborn, Keras, TensorFlow, SkLearn, OpenCV

4.2. Dataset

Dataset: The Wildfire Dataset-

https://www.kaggle.com/code/dima806/wildfire-image-detection-vit/input?select=the_wildfire_dataset

- The Wildfire Dataset is a component of the effort to explore the potential of RGB imaging technology in the domain of forest fire detection through Machine Learning.
- It spans 2,700 aerial and ground-based images, capturing a wide spectrum of environmental scenarios, forest variants and geographical locations.[7]
- The training data (70%) comprises 1888 images, the validation data (15%) comprises 402 images for parameter fine-tuning, and the test data (15%) comprises 410 images for final model evaluation.
- Each image has an average size of 4057×3155 pixels. The minimum image size is 153×206 pixels, and the maximum image size is 19699×8974 pixels.
- The dataset has been designed for Binary Classification. There are two primary classes: nofire (1653 images) and fire (1047 images) [7].

  Each primary class has further subdivisions:

  1. nofire:
  Forested areas without confounding elements (Total: 847 images).
  Fire confounding elements (Total: 336 images).
  Smoke confounding elements (Total: 471 images).

  2. fire:
  Smoke from fires (Total: 662 images).
  Both smoke and fire (Total: 384 images).

CHAPTER V: PLAN OF WORK

5.1. GANTT Chart

Task No.	Task Description	Duration	Week 1	Week 2	Week 3	Week 4	Week 5	Week 6	Week 7
w	Group Formation	1 day							
2.	Domain Identification	1 day							
3.	Identification of Project Title	1 day							
4.	Searching for Papers	2 days							
5.	Searching for Databases and looking at GitHub code	1 day							
6.	Data Collection and Preparation	1 day							
7.	Image Processing and Analysis	2 days							
8.	Feature Extraction	2 days							
9.	Model Development	2 days							
10.	Integration with GUI	1 day							
11.	Accuracy Assessment and Validation	2 days							
12.	Documentation and Reporting	3 days							
13.	Cloud Deployment	1 day							

Table 5.1.: GANTT Chart

Group Member 1: Aparna Iyer: Task 1, 2, 3, 4, 5, 6

Group Member 2: Task 2, 3, 4

Group Member 3: Task 1, 2, 4, 6

Group Member 4: Task 1, 2, 4, 5

CHAPTER VI: LEARNING OUTCOMES

The wildfire detection project using digital image processing of satellite image data, can provide valuable learning outcomes across various domains, including remote sensing, data analytics, environmental science, emergency management, and interdisciplinary collaboration.

Some potential learning outcomes for the project are:

1. Remote Sensing and Image Analysis:
    - Understanding satellite sensors, data acquisition techniques, and image processing algorithms used for wildfire detection and monitoring,
    - Proficiency in interpreting satellite imagery, identifying wildfire-related features, and extracting relevant information using remote sensing techniques.
    - Hands-on experience with software tools and platforms for satellite data analysis, such as image processing libraries and machine learning frameworks.

2. Data Analytics and Machine Learning:
    - Knowledge of data analytics methods, statistical techniques, and machine learning algorithms applied to wildfire detection, classification, and prediction.
    - Ability to preprocess, analyse, and visualize large volumes of satellite imagery and associated geospatial data to extract actionable insights and patterns.
    - Experience in developing and evaluating predictive models and decision support systems for wildfire management based on satellite image data.

3. Environmental Science and Wildfire Ecology:
    - Understanding wildfire dynamics, fire behaviour, and ecological impacts on ecosystems, vegetation, and wildlife habitats.
    - Awareness of the role of climate change, land use patterns, and human activities in influencing wildfire occurrence, severity and distribution.
    - Insights into the integration of satellite-based observations with field-data, ecological models, and environmental indicators to assess wildfire impacts and inform ecosystem management strategies.

4. Emergency Management and Disaster Response:
    - Familiarity with wildfire management practices, emergency response protocols, and risk assessment methodologies used by government agencies, fire departments, and disaster management organizations.
    - Knowledge of wildfire risk assessment, evacuation planning, community resilience strategies, and public communication strategies to mitigate the impacts of wildfires on human communities and infrastructure.
    - Experience in developing early warning systems, decision support tools, and situational awareness platforms for wildfire preparedness and response based on satellite image data.

5. Interdisciplinary Collaboration and Communication:

- Communication skills to effectively convey technical concepts, data-driven insights, and policy recommendations to diverse audiences, including policymakers, practitioners, and the general public.
- Appreciation of the importance of interdisciplinary collaboration, stakeholder engagement, and participatory approaches in addressing wildfire risks and promoting community resilience.

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