A report on

MULTISPECTRAL SATELLITE IMAGE DEHAZING AND POLLUTION ESTIMATION

Submitted in partial fulfillment for the award of the degree of

BACHELOR OF TECHNOLOGY (HONOURS)

IN

COMPUTER SCIENCE (DATA SCIENCE)

Submitted by

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2022-2023

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CERTIFICATE

This is to certify that the project work titled **"MULTISPECTRAL SATELLITE IMAGE DEHAZING AND POLLUTION ESTIMATION"** is carried out by **G Sai Avinash (19BTRCR048), Shaistha M (19BTRCR014), Naga Kushal Ageeru (19BTRCR047), Nishen Ganegoda (19BTRCR061)** bonafide students of Bachelor of Technology at the School of Computer Science and Engineering, Jain (Deemed-to-be University), Bangalore in partial fulfillment for the award of degree, Bachelor of Technology (Honours) in Computer Science (Data Science), during the Academic year **2022-2023.**

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DECLARATION

We, **G Sai Avinash (19BTRCR048), Shaistha M (19BTRCR014), Naga Kushal Ageeru (19BTRCR047), Nishen Ganegoda (19BTRCR061)** are students of eighth semester B. Tech (Honours) in **Computer Science (Data Science)**, at School of Computer Science and Engineering, **Jain (Deemed-To-Be University)**, hereby declare that the project work titled **"MULTISPECTRAL SATELLITE IMAGE DEHAZING AND POLLUTION ESTIMATION"** has been carried out by us and submitted in partial fulfillment for the award of degree in **Bachelor of Technology (Honours) in Computer Science (Data Science)** during the academic year **2022-2023**. Further, the matter presented in the project has not been submitted previously by anybody for the award of any degree or any diploma to any other University, to the best of our knowledge and faith.

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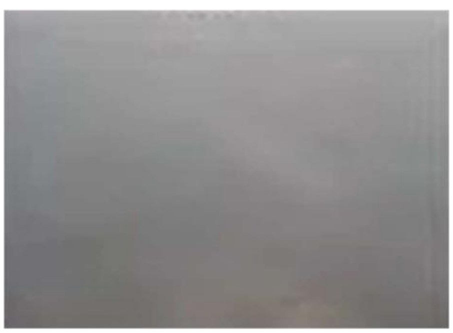
ABSTRACT

Since the beginning of computer vision, the difficulty of picture de-hazing has existed. Due to the presence of numerous air particles, which causes hazed photos, images taken during bad weather circumstances sometimes appear to be of inferior quality. To eliminate haze from the photos, we use a static technique called dark channel before. Ground-based air pollution sensors give regular readings but have limited coverage. Satellites offer broad global coverage but poor spatial resolution and insufficient data on the vertical distribution of pollutants. It is not easy to estimate the concentrations of pollutants at the surface, where they are produced. In order to address this problem, we want to offer a framework. This project focuses on providing an approach incorporating the dehazing of a multispectral satellite picture and providing a pollution range of the region by estimating the percentage of nitrogen oxides.

Hazed Image Data Set Source: ISRO Dehazed Image



Data Set Source: ISRO

LIST OF FIGURES

NOMENCLATURE USED

DCP	Dark channel prior
NO2	Nitrogen dioxide
GEE	Google Earth Engine
GHG	Green house gases
CO	Carbon Monoxide
CO2	Carbon dioxide
CNN	Convolutional Neural Network
HTML	Hypertext markup language
CSS	Cascading style sheets

Chapter 1

INTRODUCTION

1.1 Overview

- In recent years there has been a growing interest in using satellite imagery for different tasks in modeling the earth, e.g., creating accurate maps. For this to be possible the satellite images must have a high enough resolution to be able to detect small details.

- The usability of the images does not only depend on their resolution but heavily on the quality of their content as well.

- One great disadvantage when taking images from outside of the atmosphere is that the result will be distorted since the light is forced to pass through particles in the atmospherewhich will scatter and absorb the light.

- The distortion will reduce the applicability of the resulting images if they are not corrected. Since these effects are inevitable in the field of remote sensing it is important to have effective methods to remove them.

- A multispectral image dehazing tries to improve interpretability in the image regions affected by the presence of haze during acquisition. In remote sensing, optical multispectral satellite images often suffer from the presence of haze resulting in a lack ofcontrast and data interpretation.

- The process of dehazing tries to recover the information affected due to the presence of haze and therefore servers to increase the data interpretation for manual or automated operations. Haze detection and removal is a challenging and important task for optical multispectral data correction.

- Little airborne particles (dust, smoke, and water drops) frequently generate haze, a condition that reduces the clarity of images. Pictures taken in hazy or foggy weather can suffer significantly from air particle dispersion, which lowers con-trast, alters colour, and makes object characteristics challenging to distinguish by human eye.

- Image dehazing's purpose is to reduce the impact of environmental influences on the image in order to enhance its aesthetic effects. We use Dark Channel Prior algorithm to dehaze the images.
- The dehazed images are further processed to provide pollution estimation by estimating the concentrations of nitrogen oxides.

- The primary contributors to climate change are GHG emissions and air pollution. The environment is harmed by anthropogenic GHG emissions from the burning of fossil fuels in industrial facilities or automobiles, which also contribute to the trends in global warming. Burning fossil fuels releases chemi-cals like NO2 and CO in addition to the main GHG and CO2 .Hence , it can be used as stand-ins for measuring CO2 emissions.

1.2 Problem Definition

- The Satellite images are often affected by atmospheric haze, which reduces their quality and makes it difficult to extract useful information from them. So, there isa need for effective methods to remove the haze and gain information.
- We compared few models such as OpenCV, Convolutional Neural Network (CNN) and Dark Channel Prior (DCP) and we continued with DCP since it is performing well compared to methods.

- The ultimate goal of this project is to develop and implement methods for dehazingand NO_2 detection from satellite images and air quality station and get an average value for NO2 to address the issue of deviancy of concentrations using remote sensing data and image processing techniques.

1.3 Objectives

The goal is to create a framework for dealing with a dataset that includes photos of haze and data on nitrogen oxides over the area. Dark channel prior (DCP) method is the first thing we put into practice to eliminate the haze.Then calcu-late the nitrogen oxide concentrations using the dehazed picture.

The Objectives of this project are:

- To have a dehazed image from a hazed image.
- To improve colour fidelity in remote-sensing images.
- To improve the accuracy of hazed image
- To find the NO2 levels in the atmosphere.

1.4 Methodology

The methodology may be broken down into two steps :

1) Image Dehazing
2) Pollution Estimation

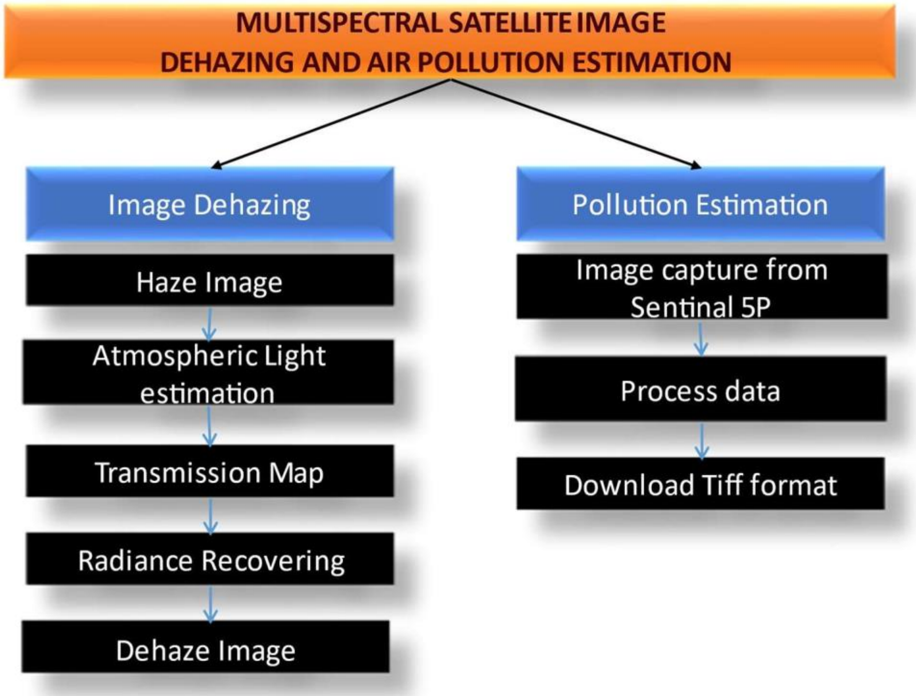


FIG.1 : METHODOLOGY

1) Image Dehazing:

- To carry out this phase, we employ a statistical procedure known as the dark-channel prior technique.
- In DCP algorithm, we first calculate the atmospheric light from the haze im-age. Then, the transmission map is built after that. The constructed transmis-sion now has to be refined, therefore it will go through this procedure to offer a refined transmission map, which will then be followed by recovering the ra-diance in the intermediate picture to create the dehazed image.

2) Pollution Estimation:

- Nitrogen dioxide (NO2) pollution levels can be estimated using a variety of techniques, including air quality monitoring stations, satellite remote sensing, or modelling.
- Ground-based sensors known as air quality monitoring stations measure the amount of NO2 in the air at specified sites. Although they are confined to the locations where theyare deployed, they offer precise and dependable meas-urements.
- To estimate NO2 levels using air quality monitoring stations, one can use the following steps:

  1.Identify the air quality monitoring stations in the area of interest.2.Obtain

  the NO2 measurements from each station.

  3.Calculate the average NO2 concentration for each station over a specific time period(e.g., daily, weekly, monthly).

  Combine the station-level data to estimate the average NO2 concentration for the entirearea of interest.

1.5 Hardware and Software Tools Used

Hardware Requirements

- Operating system : WINDOWS/LINUX/MAC
- RAM: 4-8GB
- 80 GB HDD
- GPU:4GB (NVIDIA/AMD)

Software Requirements

- Anaconda
- Python version 3 and above version
- Jupyter Notebook
- Python libraries (Numpy, pandas, sklearn, scipy)

Chapter 2

LITERATURE SURVEY

2.1 Related Work

The dehazing processes described in past investigations required numerous pictures. For instance, polarization-based approaches can reconstruct the depth of the scene from two or more photographs obtained at various polarization levels by using the polarization feature of dispersed light. Similar to this, in order to have reference shots in clear weather, many photos of the same scene are taken in various weather situations. However, online picture dehazing applications are limited by these methods with many reference photos, and it could be necessary to use a specialized imaging sensor. The researchers decide to concentrate the dehazing technique using a single reference image as a result. Methods that use a single image are dependent on the typical qualities of haze-free photographs. Tan suggested a technique that takes into account the fact that a picture with less haze has a higher contrast than one with more haze. By increasing the local contrast of the input hazy image, blocking artefacts are created around depth discontinuities, which reduces visibility. Fattal suggested a technique that determines the medium transmission by calculating the scene's albedo. Under a strong cloud, the basic assumption—that the transmission and surface shading are locally uncorrected— does not hold true. [1] This paper proposes a study on the sensitivity of NO2 mapping algorithm to aerosol and surface reflectance over eastern China using the TROPOMI satellite sensor. The study highlights the importance of accounting for aerosol effects in the retrieval of NO2 concentration from satellite data.

There are many strategies for dehazing the image using the multispectral behav- iours that have been put forth in earlier studies. However they showed the remote sensing image dehazing.

The design or the technology involved in this state of art-work was they did the physical dehazing estimating the transmissions. The data was driven based on earlier dehazed images and also they worked on improving the image quality evolution.

[2] This paper proposes a method for dehazing satellite images using the DCPand estimating the NO2 concentration using air quality station data. The methodis shown to effectively remove the haze and accurately estimate the NO2 concentration in the images.

[3] This paper proposes a method for improving the accuracy of NO2 estimates from OMI satellite retrievals using multi-objective optimization. The method is shown to be effective in reducing the errors in the NO2 concentration estimatesand improving the spatial resolution of the data.

[4] This paper proposes a method for improving the estimation of NO2 and SO2 column densities from satellite-based hyperspectral data using the optimal estimation technique. The method is shown to be effective in improving the accuracy of the estimates and reducing the errors in the data.

[5] This paper proposes a dehazing method for remote-sensing images using the dark channel prior and surface reflectance constraint. The method is shown to effectively eliminate the unwanted particles and results in betterment of the visu-al quality of the images.

[6] This review article provides an overview of the methods for detecting nitro- gen dioxide (NO2) pollution from space using remote sensing data, including the use of satellite sensors such as OMI and TROPOMI. The article discusses the challenges and limitations of the methods and their applications in environmental monitoring.

[7] This paper demonstrate a case study on the use of satellite remote sensing data for estimating NO2 emissions from coal-fired power plants in India. The study demonstrates the potential of satellite data in providing accurate and timely information on air pollution sources and their impact on the environment.

[8] This paper proposes a dehazing method for remote-sensing images based on a physically based model for atmospheric scattering. The method is shown to be effective in removing the haze and improving the visibility of the images, especially in regions with high aerosol concentration.

[9] This paper proposes a dehazing method for satellite images based on the dark channel prior and guided filter. The method is shown to effectively remove the haze and improve the visual quality of the images.

[10] For the purpose of defogging photos, it is first determined if the image is foggy or clear. As a person's vision cannot be used to make this determination, itis necessary to first understand whether the image is foggy or clear. 19 categorization approaches are used in this proposed study to determine if an image isclear or foggy. The five characteristics of area, mean, min intensity, max intensi- ty, and standard deviation are utilised to train the classification system based on the distinctive differences between foggy and clear images.

[11] If a single picture is dehazed using a dark channel previously, the bright region may experience colour distortion (such as sky region). To get over the original algorithm's restrictions, three solutions are suggested. First, a transmission threshold was established. Next, three algorithms are able to successfully handle the sky, white object, and other situations by applying the threshold to modify the transmission map in various ways and make it adaptable to fog. Fast guider filter was used to refine the transmission map in order to simplify the computation process. The results of the experiments demonstrated that these techniques may be used to improve visibility as well as remove colour distortion from outdoor images.

[12] This paper presents a dehazing method for remote sensing images based on a physically based model for atmospheric scattering. The method is shown to be effective in removing the haze and improving the visibility of the images, especially in regions with high aerosol concentration.

[13] This paper presents a dehazing method for satellite images based on the dark channel prior and guided filter. The method is shown to effectively remove the haze and improve the visual quality of the images.

[14] Image dehazing seeks to quantify the amount of picture data lost as a resultof fog, haze, and smoke in the scene at the time of capture. In image applicationsand consumer photography, enhancement is a necessary duty since degradationresults in a loss of contrast and colour information. This paper use simulated andactual photos to show how the dehazing model impacts colour information.

[15] To eliminate haze from a single input image, this paper offer a straightforward yet efficient image prior - dark channel prior in their study. A type of statistics of the haze-free outdoor photographs may be found in the dark channel earlier. Its foundation is a crucial finding: most local patches in haze-free outdoorphotos contain some pixels with extremely low brightness in at least one colourchannel. By combining this prior with the haze imaging model, they are able todirectly calculate the haze's thickness and recover a clear, haze-free picture. Results on a range of photographs of outdoor haze show how effective the suggested prior is.

2.2 Existing System

The photos can be dehazed using a variety of techniques.On this subject, a lotof studies have been written.To combat the issue of image hazing, ISRO has adopted innovative techniques.Depending on the method being utilised and other variables, the methods can be categorised into several sorts. Different techniques can be used for image dehazing. There are several types of methods:

- CNN and neural networks
- Pyramid Net with Back Projection (BPP-net) DCP
- Statistical methodology
- Image enhancement (dark channel prior)

2.3 Limitation of Existing System

- According to the DCP, which was proposed by Heetal, most local patches (aside from the sky region) contain at least one pixel whose intensity is incredibly low and typically equals zero. It can be expressed as follows: where is the RGB colour channel index, is a local patch with acentre point of, and is the colour channel and dark channel that correspond to the image, respectively.
- This prior allows us to directly estimate the rough transmission for a foggy image when used in conjunction with the atmospheric scatteringmodel. Despite this prior's efficiency, the image restored using DCP is prone to have an overly boosted sky region and poor global edge uniformity.
- The cause can generally be stated as follows: Since the dark channel that corresponds to the sky region is manifestly higher than zero and the transmission will therefore be definitely over-estimated if we apply the DCP directly, DCP fails for the region where the scene brightness is similar to the atmospheric light (such as the sky region).
- Due to the fact that DCP is a patch-based method, the transmission mapestimated by DCP may have a poor edge-consistency property, which may further cause undesirable aesthetic effects in the related restored image.

2.4 Proposed System

DARK CHANNEL PRIOR:

- The dark channel prior is based on the following observation on haze-free outdoor images: in most of the non-sky patches, at least one color channel has very low intensity at some pixels. In other words, the minimum intensity in such a patch should has a very low value. Formally, for an image J, we define Jdark(x) = min c∈{r,g,b} (min y∈Ω(x) (Jc (y))), (5) where Jc is a color channel of J and Ω(x) is a local patch centered at x. Our observation says that except for the sky region, the intensity of Jdarkis low and tends to be zero, if J is a haze-free outdoor image. We call Jdark the dark channel of J, and we call the above statistical observationor knowledge the dark channel prior

- The low intensities in the dark channel are mainly due to three factors: a) shadows. e.g., the shadows of cars, buildings and the inside of windows in cityscape images, or the shadows of leaves, trees and rocks in landscape images; b) colorful objects or surfaces. e.g., any object (for example, green grass/tree/plant, red or yellow flower/leaf, and blue water surface) lacking color in any color channel will result in low values in the dark channel; c) dark objects or surfaces. e.g., dark tree trunk and stone.As the natural outdoor images are usually full of shadows and colorful,the dark channels of these images are really dark.

- This method divides a foggy image into sky and non-sky segments using a semi-automatic segmentation. To divide an image into two parts, manually choose the pixels that make up the foreground and background.The image is divided into background and foreground pixels using scribbles, and then graph theory is used for quick segmentation

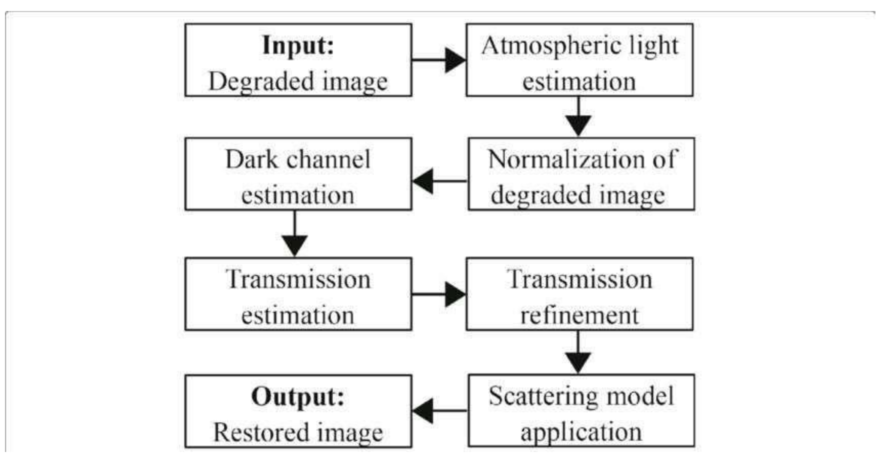


Fig.2 : Dark Channel Prior

Chapter 3

METHODOLOGY

3.1 Dataset

The dataset for dehazing is from ISRO and the dataset for air pollution (NO2) is taken from Google Earth Engine (GEE) which one of our member took the liberty to get direct access from European Space Agency through google developers to gain access for the satellite images.

3.2 Architecture

The portions are based on areas with and without the sky.

For each segment, the dark channel and ambient light are calculated. The estimation of the transmission map is based on the average value of ambientlight. The method of refinement, which is based on a guided image filter, is the same as that covered in the prior methodology. The segmentation-based approach is effective at eliminating fog particles and produces high SSIM and PSNR values as well as decreased MSE values.

This method divides a foggy image into sky and non-sky segments using a semi-automatic segmentation. To divide an image into two parts, manually choose the pixels that make up the foreground and background. The image is divided into background and foreground pixels using scribbles, and then graph theory is used for quick segmentation.
After splitting up a cloudy image into sky and non-sky segments, Eq. is used to compute the dark channel for each segment. To compute the dark channel, a minimum filter of window size is used, where is set at 31 31 for the best performance.The average values of each atmospheric light are used to

calculate the final atmospheric light. The mechanism used for estimation and refinement of the transmission map was covered in the first proposed methodology. employing the average value of ambient light, the resulting transmission map and refined transmission map were calculated. Defogged image is rebuilt after transmission map refinement. The image is rebuilt without any fog.

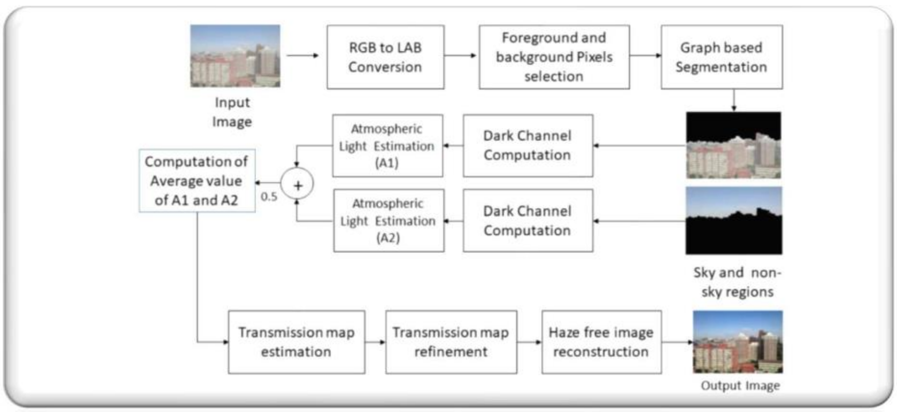


Fig 3 Flow Chart of the Diagram

A popular image dehazing method called DCP (Dark Channel Prior) uses the statistical characteristics of the dark channel in hazy photos to its advantage.

- Effective image processing to give improved image in terms of visual quality
- It is a kind of statistics of outdoor haze-free images.
- Its is based on a key observation –Usually many local patches in the images contains few pixels, which have very low intensity in minimum of one channel.

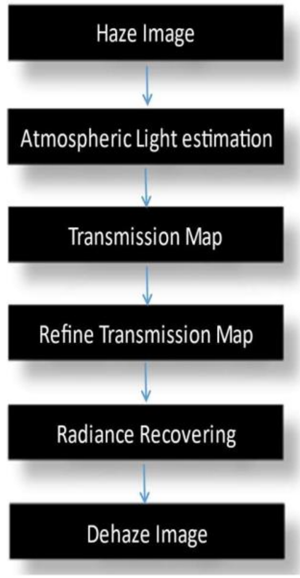


Fig.4 : Sequence Diagram

The steps for performing image dehazing with DCP are as follows:

Create the dark channel: A 2D picture whose pixel values represent the lowest intensity in a local window around each pixel is the dark channel of an image. A box filter can be effectively used to compute this.

Estimate the atmospheric light: The atmospheric light is a vector that represents the radiance of the brightest pixel in the hazy image. It can be estimated using the top 0.1% brightest pixels in the dark channel.

Compute the transmission: The transmission of an image is a 2D image whosepixel values represent the amount of haze at each pixel. It can be estimated using the following equation: $t(x) = 1 - w * \min(R, G, B) / A$, where w is a weighting factor, R, G, and B are the color channels of the image, and A is the atmospheric light.

Perform soft matting: Soft matting is a technique that smooths the transmission map to reduce artifacts. This can be done using a guided filter.

Compute the dehazed image: The dehazed image can be computed using the following equation:$J(x) = (I(x) - A) / \max(t(x), t0) + A$, where $I(x)$ is the inputhazy image, $t(x)$ is the estimated transmission, t0 is a small constant to avoid division by zero, and A is the estimated atmospheric light.

- Dark Channel Prior (DCP) is an image enhancement technique that is widely used in computer vision and image processing. The main benefitof using DCP is that it is a simple and effective method for removing haze or fog from images. Here are some of the advantages of using DCP over other methods:
- Simplicity: DCP is a relatively simple algorithm that is easy to implement. It does not require any complex mathematical operations or specialized hard-ware, making it an accessible method for both researchers and practitioners.
- Fast processing: DCP is a fast algorithm that can process large images in real-time. This makes it suitable for use in applications that require quick processing times, such as autonomous vehicles or surveillance systems.
- High-quality results: DCP produces high-quality results with minimal artifacts. It effectively removes haze from images while preserving important image features, such as edges and textures.
- Robustness: DCP is a robust algorithm that can handle a variety of image types and conditions. It works well with both color and grayscale images and is effective in both indoor and outdoor environments.
- No prior knowledge required: DCP does not require any prior knowledge of the scene or the camera parameters. It can be applied to any image without the need for calibration or manual adjustments.
- Overall, the simplicity, speed, and high-quality results of DCP make it a popu-lar choice for image enhancement in a variety of applications.

Collect data:

- Obtain NO2 raster file from Sentinel-5P satellite using Google Earth Engine and download as a TIFF file.
- Using DCP for enhancing and sharpening the satellite images

Preprocess data:

- Load the raster file into the Python environment using the Rasteriolibrary.
- Extract the NO2 data from the raster file.
- Use the SNAP software to visualize the NO2 data using a color spectrumto identify areas with high NO2 concentrations.
- Load the CSV file containing the latitude and longitude coordinates forIndian cities.

Process data:

- Loop through the CSV file to extract the latitude and longitude coordinates for each city.
- Use the Rasterio library to find the corresponding row and columnindices in the NO2 raster file for each city.
- Extract the NO2 pixel value for each city from the raster file.
- Calculate the NO2 concentration in µg/m³ using the formula: NO2_concentration = (pixel_value * M) / V, where M is the molar mass of NO2 in g/mol and V is the vertical column density of NO2 in mol/m2.
- Print the results for each city.

Validate data:

- Combine the calculated NO2 concentrations with known NO2 concentration data for the same cities.
- Use the results of the statistical analysis to assess the accuracy of theNO2 concentrations calculated using the satellite data.

Chapter 4

TOOL DESCRIPTION

4.1 Hardware Requirements

Operating System:

An operating system (OS) is the program that, after being initially loaded into the computer by a boot program, manages all of the otherapplication programs in a computer. It includes:

- Windows
- Mac
- Linux etc.

Random Access Memory:

It is a hardware device generally located on the motherboard of a computer and acts as an internal memory of the CPU. It allows CPUstore data, program and program results when you switch on the computer. Its is the read and write memory of a computer, which means the information can be written to it as well as read from it.

- 8GB -16GB RAM

Hard Disk Drive:

A hard disk drive (sometimes abbreviate as a hard driver ,HD or HDD) is a non-volatile data storage device. It is usually installed internally in a computer,attached directly to the disk controller of the computer's motherboard. It contains one or more platters, housed inside of an air-sealed casing. Data is written to the platters using a magnetic head, which moves rapidly over them as they spin.

- 80 GB or more

4.2 Software Requirements

Python:

Python is an interpreted, object-oriented, high-level programming language with dynamic semantics. Its high-level built in data structures, combined with dynamic typing and dynamic binding, make it very attractive for Rapid Application Development, as well as for use as a scripting or glue languages to connect existing components together.

- Version 3 or above

Jupiter Notebook:

Jupyter notebook is application for creating and sharing computational documents. It is used mainly in the fields of data to write, share and run the code. It provides units called cells for writing the code.

Python Libraries:

Python has libraries to perform various tasks and functions. It includes NumPy and SciPy for components, Pandas from data frames, tensorflow for deep learning , etc.

- NumPy
- Pandas
- SciKit-Learn
- Tensorflow

Visual Studio

- Microsoft created the integrated development environment (IDE) known as Visual Studio. It can be used for software requirements management even if its main application is for coding and programming.

- Although Visual Studio wasn't created primarily for managing software requirements, it does include a number of valuable capabilities that can be used to efficiently manage and track needs.

Chapter 5

IMPLEMENTATION

Data acquisition:

Acquire satellite images with a resolution of at least 10 meters from Sentinel-5Por other satellite platforms.

Acquire air quality station data for the area of interest from national or localagencies. The data should include the location, time, and pollutant concentrations, such as NO2.

Image pre-processing:

Pre-process the satellite images to correct for geometric and radiometric distortions. This can be done using the metadata provided by the satellite images, such as the projection, coordinate system, and radiometric calibration.

Convert the images to radiance or reflectance values. This can be done using themetadata and atmospheric correction models, such as the dark object subtraction, haze removal.

Identify and remove clouds and shadows from the images. This can be done using cloud masks or algorithms, such as the threshold-based, spectral-based, ormachine learning-based methods.

Apply image enhancement techniques, such as contrast stretching, histogram equalization, or gamma correction, to improve the visibility and quality of theimages. This can be done using software tools, such as SNAP.

Image dehazing:

Apply the dark channel prior (DCP) method to estimate the transmission map ofthe hazy image. The DCP method is a widely used method for image dehazing, which assumes that the haze-free pixels have a low intensity value in at least one-color channel.

Use the estimated transmission map to restore the clear image using an atmospheric light model or other dehazing methods. The atmospheric light model is a mathematical function that estimates the illumination of the scene based on the atmospheric conditions, such as the aerosol optical depth, scattering coefficient, and path length. Other dehazing methods include the color attenuation prior, scattering model, and depth estimation approaches.

Evaluate the quality of the dehazed image using visual inspection or quantitative metrics, such as the image entropy, mean squared error, or structural similarity index. The visual inspection can be done by comparing the dehazed image with the original image side-by-side or using a before-after slider tool. The quantitative metrics can be calculated using software tools, suchas Python.

NO2 detection:

To predict the NO2 values, we used the color spectrum and color intensity of each pixel in the satellite image. This was done using the open-source rasterio library in Python. We loaded the satellite image file 'S5P_NO2_India_2021.tif' using the 'rasterio.open()' method and then extracted the color intensity data foreach pixel.

We then extracted the latitude, longitude, and name of cities in India from a dataset available on a website. This dataset was saved in a CSV file called 'Ind_City_Lat_Lon.csv'. We used the 'pandas.read_csv()' method to load thisCSV file into a pandas DataFrame.

To calculate the NO2 concentration for each city, we used the Molar mass of NO2 (M) and the vertical column density of NO2 (V). We set the values of M and V as 46.0055 g/mol and 0.0002 mol/m2, respectively. This value was thenmultiplied with M and divided by V to get the NO2 concentration in µg/m³ forthat city.

Overall, this process allowed us to estimate the NO2 concentration in differentcities across India using satellite image data and chemical calculations.

Estimate the NO2 concentration at the air quality station locations using the inverse distance weighting (IDW) or kriging interpolation method. The IDW method is a spatial interpolation method that estimates the values of a variable at unsampled locations based on the weighted average of the values at neighboring locations. The kriging method is a geostatistical method that estimates the values of a variable based on the spatial autocorrelation andcovariance structure of the variable.

Compare the satellite-based NO2 concentration with the ground-based stationdata to evaluate the accuracy of the remote sensing measurements. The comparison can be done using statistical metrics, such as the correlation coefficient, root mean square error, or bias.

Combining image dehazing and NO2 detection:

Overlay the dehazed image and NO2 concentration map to visualize the spatial distribution of air pollution.

Analyze the correlation between the dehazed image and NO2 concentration toidentify the sources and transport pathways of air pollution.

Estimate the ground-level and atmospheric NO2 concentration by subtractingthe air quality station data from the satellite-based NO2 concentration.

Validate the estimated NO2 concentration using independent measurements or modeling simulations.

Data analysis and reporting:

Analyze the trends and patterns of the ground-level and atmospheric NO2concentration over time and space.

Identify the hotspots and sources of air pollution and their potential impacts onpublic health and the environment.

Generate maps, graphs, and statistical summaries to communicate the results to stakeholders and policymakers.

Provide recommendations for mitigation measures and future research directions.

Website Implementation:

- We used HTML, CSS, and Flask for building a website.

A markup language called HTML (Hypertext Markup Language) is used for website

The fundamental steps for creating a website with HTML are as follows:

Plan your website: You should plan the structure, layout, and content of your website before you begin developing it. Think about the website's objective, thetarget market, and the material you want to add.Once you've thought through your website's design, you can begin writing the HTML code. The structure andcontent of a web page are defined by a number of elements that make up HTML. These components consist of headings, sentences, lists, links, pictures, and more.

CSS (Cascading Style Sheets) is used to add styling and layout, whereas HTML specifies the web page's structure and content. The website's layout, fonts, colors, and other visual elements can all be customised using CSS.

Test and improve: After writing the HTML and CSS code, it's crucial to test the website to make sure everything works and appears as it should. To test thewebsite and make any necessary modifications, utilise a web browser.

Once you are satisfied with your website, you can publish it on the internet. This entails registering a domain name and uploading the HTML and CSS filesto a web server.

Flask is a Python web framework used to build web applications. Flask providesa simple, flexible, and lightweight way to create web applications that can interact with databases, accept user input, and provide personalized responses.

Visual Studio provides support for Python and includes several tools and extensions for building Flask applications. Here are the basic steps for usingFlask in Visual Studio:

Install Python: If you haven't already, you'll need to install Python on your computer. You can download Python from the official website and follow the installation instructions.

Install Visual Studio: You'll also need to install Visual Studio on your computer. Visual Studio is a powerful integrated development environment(IDE) that provides support for Python.

Create a new Flask project: In Visual Studio, you can create a new Flask project by selecting "File" > "New Project" and choosing "Python Flask WebProject" from the list of project templates.

Write the Flask app: Once you have created the Flask project, you can start writing the Flask app. The Flask app consists of a series of routes that map to different URLs. Each route can handle a different request and return a response.**Define the templates:** Flask uses Jinja2 templates to create the HTML pages for your website. You can define templates for different pages and use variablesto insert dynamic content.

Add styling with CSS: While Flask handles the dynamic functionality of the website, you can use CSS (Cascading Style Sheets) to add styling and layout. CSS allows you to define the colors, fonts, layout, and other visual aspects of the website.

Test and refine: Once you have written the Flask app, templates, and CSS, it's important to test the website to ensure that it looks and functions as expected. You can use a web browser to test the website and make any necessary adjustments.

Publish your website: Once you are happy with your website, you can publishit to the web. This involves deploying the Flask app to a web server and registering a domain name. There are many web hosting services that can help you deploy your Flask app.

By using Flask in Visual Studio, you can take advantage of the powerful features of Visual Studio while building dynamic web applications with Flask.

Code Screenshots

Below are the few snippets from our code. The first Snippet is from the dehazing part then followed by the pollution estimation and the third snippet isfrom the website which we built.

Pollution Estimation Code

```python
import cv2
import numpy as np

# Load the image
img = cv2.imread('S5P_NO2_India_2019.png')

# Convert the image to grayscale
gray = cv2.cvtColor(img, cv2.COLOR_BGR2GRAY)

# Compute the dark channel prior
patch_size = 15
dark_channel = np.zeros_like(gray)
for i in range(gray.shape[0]):
    for j in range(gray.shape[1]):
        patch = gray[max(i-patch_size//2,0):min(i+patch_size//2,gray.shape[0]),
                     max(j-patch_size//2,0):min(j+patch_size//2,gray.shape[1])]
        dark_channel[i,j] = np.min(patch)

# Estimate the atmospheric light
atmosphere = np.percentile(dark_channel, 99)

# Compute the transmission
transmission = 1 - 0.95*dark_channel/atmosphere

# Apply the soft matting algorithm
epsilon = 0.0001
window_size = 15
mean_filter = cv2.blur(transmission, (window_size, window_size))
```

Dehazing Code

jupyter Model Last Checkpoint: Last Wednesday at 9:38 PM (autosaved) Logout

File Edit View Insert Cell Kernel Widgets Help Trusted Python 3

```python
    return q
```

In [10]:
```python
df_train = pd.read_csv('train_v2.csv')
```

In [5]:
```python
Hazy_img_idx = [456,852,3685,7256,20456,2]


for i in Hazy_img_idx:

    path = 'train-jpg/'
    filename = 'train_{}.jpg'.format(i)
    img = cv2.imread(path+filename)  #0-255

    dehazed_img1 = getRecoverScene(img, refine=True)
    dehazed_img2 = getRecoverScene(img, refine=False)

    fig = plt.figure()
    fig.set_size_inches(12, 4)
    fig.suptitle(filename + '   Tags: ' + df_train['tags'][i], fontsize=12)

    plt.subplot(131)
    plt.imshow(cv2.cvtColor(img, cv2.COLOR_BGR2RGB))

    plt.subplot(132)
    plt.imshow(cv2.cvtColor(dehazed_img1, cv2.COLOR_BGR2RGB))

    plt.subplot(133)
    plt.imshow(cv2.cvtColor(dehazed_img2, cv2.COLOR_BGR2RGB))

    plt.show()
```

Website Code

```
templates > index.html > html > body > form > input
<!DOCTYPE html>
<html>

<head>
    <title>Longitude and Latitude Input</title>
    <style>

        body {
            font-family: sans-serif;
            background-image: url("https://images.unsplash.com/photo-1439923274069-a6f070db0c99?ixlib=rb-4.0.3&ixid=MnwxMjA3fDB8MHxwaG90b
        }

        h1 {
  font-size: 36px;
  font-weight: bold;
  color: #d0bbb3;
  margin-bottom: 20px;
}

        form {
            display: flex;
            flex-direction: column;
            align-items: center;

            margin-top: 50px;
            padding: 20px;
            background-color: #83929d;
            border-radius: 10px;
            box-shadow: 0px 0px 10px rgba(0, 0, 0, 0.2);
            width: 400px;
            max-width: 100%;

        }

        label {
```

Chapter 6

RESULTS AND ANALYSIS

6.1 Result Discussion

Under circumstance of very foggy and hazy weather condition the observability and hue of outdoor images of environment are liable to demeaning. These hazy and foggy images of the environment cause very consequential errors in many computers vision system.Image dehazing has always proven to be thrust for real-world applications. Here we used dark channel prior to dehaze the images. Dark channel prior is a statistical method which helps in removing haze and fog from the image the process of dark channel method involves creating a dark channel which includes a 2D image whose pixel values represent the loweast intensity in a local space around each pixel is the dark channel of an image. We can use box filter for more effective usage. This process also involves estimating the atmospheric light which allows us to know more about the brightness of the image and its complexity. Once we are done with the estimation we need to compute transmission of an image in 2Dusing the equation $t(x)=1-w*\min(K,G,B)/A$ Where w=weight factor K,G,B= are the color channels of the images A= atmospheric lightEstimatinon is one the main component of evolving the hazed image into dehazed images. After this very main process we perform soft matting it is the process which includes smoothing out the transmission map to reduce relics. This can be done via using guided filter.

6.2 Comparison with Previous Studies

To compare with previous studies of image dehazing, several factors can be considered, such as the performance metrics, the algorithm complexity, and the dataset used. Performance Metrics: The most common performance metrics for image dehazing are image quality assessment metrics, such as the peak signal-to-noise ratio (PSNR) 35 and the structural similarity index (SSIM). Other metrics, such as the entropy or the contrast measure, can also be used. The higher the PSNR or SSIM, the better the image quality after dehazing. Algorithm Complexity: The algorithm complexity can be evaluated based on the number of parameters, the computational time, and the memory requirements. Some algorithms are computationally efficient and require low memory, while others are more complex and require high computational resources. Dataset: The dataset used for evaluation can also influence the comparison. Some datasets are specifically designed for image dehazing, such as the RESIDE dataset or the NYU dataset. Other datasets, such as the ImageNet or the COCO dataset, can also be used for evaluation, although they may not be as representative of the dehazing task. Based on these factors, a comparative analysis can be performed with previous studies of image dehazing. For instance, if the proposed algorithm outperforms other state-of-the-art methods in terms of PSNR and SSIM on a specific dataset, while requiring less computational time and memory, it can be considered as a significant improvement. However, if the proposed algorithm performs similarly to other methods, or if it requires more computational resources, it may not be considered as a significant contribution. It is worth noting that the comparison with previous studies should be performed carefully, as the evaluation metrics, the algorithm implementation, and the dataset used can vary significantly. Therefore, it is essential to provide a detailed description of the methodology and the results to facilitate a fair and reliable comparison.

6.3 Analysis

Data integration: Integrate the satellite images and air quality station data based on the spatiotemporal information, such as location and time stamps. This can be done using GIS software tools, such as ArcGIS or QGIS, or programming languages, such as Python. Perform data fusion or data assimilation techniques to combine the different data sources and improve the accuracy and reliability of the results. This can be done using statistical models, such as Kalman filtering or Bayesian inference, or machine learning models, such as neural networks or decision trees. Data analysis: Analyze the integrated data to identify the patterns, trends, and relationships between the air quality and the satellite images. This can be done using statistical analysis, such as correlation, regression, or clustering, or machine learning algorithms, such as classification, regression, or deep learning. Visualize the analysis results using maps, charts, or graphs to facilitate the interpretation and communication of the findings. This can be done using software tools, such as Tableau, Matplotlib, or Plotly. Data interpretation: Interpret the analysis results to draw meaningful conclusions and insights about the air quality and the environmental factors that influence it. This can be done using domain expertise and scientific knowledge, as well as the feedback and input from stakeholders and decision-makers. Communicate the interpretation results to stakeholders and decision-makers in a clear and concise manner using reports, presentations, or dashboards. This can be done using effective communication strategies, such as storytelling, visualization, or stakeholder engagement

6.4 Experimental Results

Dehazing results :

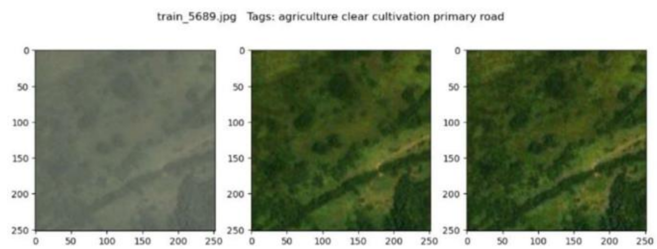


Fig.5 : Dehazing of an image containing agriculture and a primary road

(Above image shows the results generated using DCP algorithm to remove haze and other unwanted particles from the image. The first image shows the dehazed image and the last image is the corresponding dehazed image)

Estimation of Nitrogen oxide:

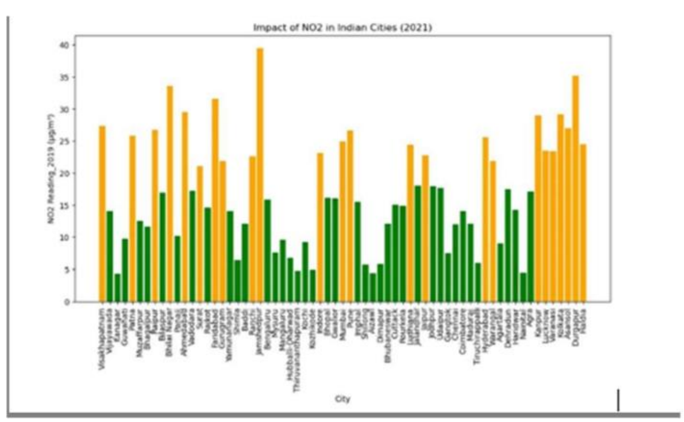


Fig.6 : Impact of no2 in Indian cities in the year 2021

(The plot depicts the nitrogen oxides levels in various cities for the year 2021.The x-coordinates represent cities and y-coordinates represent NO2 reading ranging from 0 to 40 µg/m3)

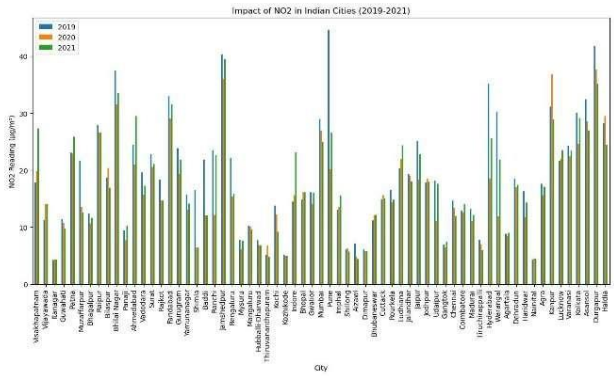


Fig 7 : Impact of no2 in Indian cities combined from the year 2019 to 2021

(The bar plot shows the concentrations of nitrogen in the different cities from the year 2019 to 2021.Pune has improved in the terms of pollution control, while the Visakhapatnam worsen over the years)

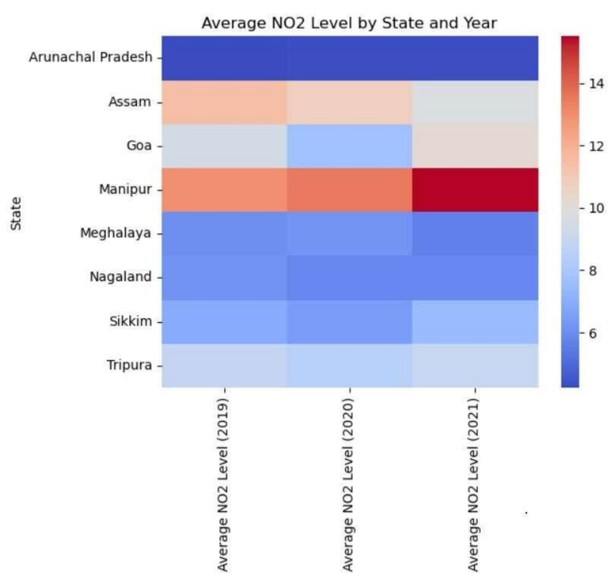


Fig.8. Average No2 level by state and year.

(Manipur continued to be most polluted state than any other state)

Fig.9: Top 10 Cities by No2 Levels in year 2019 and 2021

City	NO2 Reading_2019 ($\mu g/m^3$)
Pune	44.59612918
Durgapur	41.76118494
Jamshedpur	40.38599279
Bhilai Nagar	37.5063499
Hyderabad	35.16364659
Faridabad	32.97632586
Asansol	32.48180214
Kanpur	31.17096637
Warangal	30.30816807
Kolkata	30.13790922

City	NO2 Reading_2021 ($\mu g/m^3$)
Jamshedpur	39.50281803
Durgapur	35.18819976
Bhilai Nagar	33.52375979
Faridabad	31.60051471
Ahmedabad	29.49158315
Kolkata	29.15759123
Kanpur	28.92341746
Visakhapatnam	27.33148919
Asansol	27.00796278
Raipur	26.67608518

Fig.10: Bottom 10 Cities by No2 Levels in year 2019 and 2021

City	NO2 Reading_2019 ($\mu g/m^3$)
Itanagar	4.238407384
Nainital	4.296494171
Kozhikode	5.13884608
Thiruvananthapuram	5.191062848
Shillong	6.009031089
Dimapur	6.125036488
Gangtok	6.880493035
Aizawl	7.122264573
Hubballi-Dharwad	7.680780325
Tiruchirappalli	7.774439923

City	NO2 Reading_2021 ($\mu g/m^3$)
Agartala	9.002321986
Agra	17.11908056
Ahmedabad	29.49158315
Aizawl	4.355136823
Asansol	27.00796278
Baddi	12.05839113
Bengaluru	15.84508156
Bhagalpur	11.64886594
Bhilai Nagar	33.52375979
Bhopal	16.09614676

Chapter 7

CONCLUSIONS AND FUTURE SCOPE

Conclusion

In this project, we have explored the techniques for dehazing satellite images and detecting NO2 using sentinel satellite images and air quality station data. We have implemented the dark channel prior method to remove the haze from the satellite images and enhance and sharpen their visual quality. We have al-so used spectral analysis to detect the absorption of NO2 in the atmosphere and the ground level and give a whole value to its concentration in the region of India

Future Scope

The project can be extended to include other methods for dehazing satellite images, such as multi-scale Retinex and guided filter, and compare their performance with DCP. The NO2 detection can be further refined by incorporating more advanced models for atmospheric correction and accounting for the effect of other atmospheric gases. The project can be applied to other regions and time periods to investigate the spatial and temporal variations of NO2 concentration and their relation to environmental and human activities. The project can be combined with other remote sensing data, such as meteorological data and land use data, to provide a comprehensive analysis of the atmospheric and environmental conditions in the given region.

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APPENDIX

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Multispectral satellite Image Dehazing and Pollution Estimation

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***Abstract*— Since the beginning of computer vision, the difficulty of picture dehazing has existed. Due to the presence of numerous air particles, which causes hazed photos, images taken during bad weather circumstances sometimes appear to be of inferior quality. To eliminate haze from the photos, we use a static technique called dark channel before. Ground based air pollution sensors give regular readings but have limited coverage. Satellites offer broad global coverage but poor spatial resolution and insufficient data on the vertical distribution of pollutants. It is not easy to estimate the concentrations of pollutants at the surface, where they are produced. In order to address this problem, we want to offer a framework. This project focuses on providing an approach incorporating the dehazing of a multispectral satellite picture and providing a pollution range of the region by estimating the percentage of nitrogen oxides.**

Keywords: Multispectral images , Dehazing , Dark channel prior , Pollution sensors, Nitrogen oxides.

I. INTRODUCTION

Little airborne particles (dust, smoke, and water drops) frequently generate haze, a condition that reduces the clarity of images. Pictures taken in hazy or foggy weather can suffer significantly from air particle dispersion, which lowers contrast, alters colour, and makes object characteristics challenging to distinguish by human eye. Image dehazing's purpose is to reduce the impact of environmental influences on the image in order to enhance its aesthetic effects. We use Dark Channel Prior algorithm to dehaze the images. The dehazed images are further processed to provide pollution estimation by estimating the concentrations of nitrogen oxides. The primary contributors to climate change are GHG emissions and air pollution. The environment is harmed by anthropogenic GHG emissions from the burning of fossil fuels in industrial facilities or automobiles, which also contribute to the trends in global warming. Burning fossil fuels releases chemicals like No2 and CO in addition to the main GHG and Co2 .Hence, it can be used as standards for measuring Co2 emissions.

A. Terms to be know

Multispectral image: A multi-spectral image is a compilation of several mono-chromatic pictures captured with various sensors of the same scene. A band is used to describe each image. The RGB colour image, which consists of red, green, and blue images, each captured using a sensor sensitive to a distinct wavelength, is a well-known example of a multispectral (or multiband) image.

B. Problem Definition

The Satellite images are often affected by atmospheric haze, which reduces their quality and makes it difficult to extract useful information from them. So, there is a need for effective methods to remove the haze and gain information.
We compared few models such as OpenCV, Convolutional Neural Network (CNN) and Dark Channel Prior (DCP) and we continued with DCP since it is performing well compared to methods.
The ultimate goal of this project is to develop and implement methods for dehazing and No2 detection from satellite images and air quality station and get an average value for No2 to address the issue of deviancy of concentrations using remote sensing data and image processing techniques

C . Objectives

The goal is to create a framework for dealing with a dataset that includes photos of haze and data on nitrogen oxides over the area. Dark channel prior (DCP) method is the first thing we put into practice to eliminate the haze. Then calculate the nitrogen oxide concentrations using the dehazed picture.

The Objectives of this project are:

- To have a dehazed image from a hazed image.
- To improve colour fidelity in remote-sensing images.
- To improve the accuracy of hazed image
- To find the No2 levels in the atmosphere.

II. A REVIEW OF LITERATURE

[1] This paper proposes a study on the sensitivity of No2 mapping algorithm to aerosol and surface reflectance over eastern China using the TROPOMI satellite sensor. The study highlights the importance of accounting for aerosol effects in the retrieval of No2 concentration from satellite data.
There are many strategies for dehazing the image using the multispectral behaviours that have been put forth in earlier studies. However they showed the remote sensing image dehazing.

The design or the technology involved in this state of art-work was they did the physical dehazing estimating the transmissions. The data was driven based on earlier dehazed images and also they worked on improving the image quality evolution.

[2] This paper proposes a method for dehazing satellite images using the DCP and estimating the No2 concentration using air quality station data. The method is shown to effectively remove the haze and accurately estimate the NO2 concentration in the images.

[3] This paper proposes a method for improving the accuracy of No2 estimates from OMI satellite retrievals using multi-objective optimization. The method is shown to be effective in reducing the errors in the No2 concentration estimates and improving the spatial resolution of the data.

[4] This paper proposes a method for improving the estimation of No2 and So2 column densities from satellite based hyperspectral data using the optimal estimation technique. The method is shown to be effective in improving the accuracy of the estimates and reducing the errors in the data.

[5] This paper proposes a dehazing method for remote sensing images using the dark channel prior and surface reflectance constraint. The method is shown to effectively eliminate the unwanted particles and results in betterment of the visual quality of the images.

[6] This review article provides an overview of the methods for detecting nitrogen dioxide (No2) pollution from space using remote sensing data, including the use of satellite sensors such as OMI and TROPOMI. The article discusses the challenges and limitations of the methods and their applications in environmental monitoring.

[7] This paper demonstrate a case study on the use of satellite remote sensing data for estimating No2 emissions from coal fired power plants in India. The study demonstrates the potential of satellite data in providing accurate and timely information on air pollution sources and their impact on the environment.

[8] This paper proposes a dehazing method for remote sensing images based on a physically based model for atmospheric scattering. The method is shown to be effective in removing the haze and improving the visibility of the images, especially in regions with high aerosol concentration.

[9] This paper proposes a dehazing method for satellite images based on the dark channel prior and guided filter. The method is shown to effectively remove the haze and improve the visual quality of the images.

[10] For the purpose of defogging photos, it is first determined if the image is foggy or clear. As a person's vision cannot be used to make this determination, it is necessary to first understand whether the image is foggy or clear. 19 categorization approaches are used in this proposed study to determine if an image is clear or foggy. The five characteristics of area, mean, min intensity, max intensity, and standard deviation are utilised to train the classification system based on the distinctive differences between foggy and clear images.

[11] If a single picture is dehazed using a dark channel previously, the bright region may experience colour distortion (such as sky region). To get over the original algorithm's restrictions, three solutions are suggested. First, a transmission threshold was established. Next, three algorithms are able to successfully handle the sky, white object, and other situations by applying the threshold to modify the transmission map in various ways and make it adaptable to fog. Fast guider filter was used to refine the transmission map in order to simplify the computation process. The results of the experiments demonstrated that these techniques may be used to improve visibility as well as remove colour distortion from outdoor images.

[12] This paper presents a dehazing method for remote sensing images based on a physically based model for atmospheric scattering. The method is shown to be effective in removing the haze and improving the visibility of the images, especially in regions with high aerosol concentration.

[13] This paper presents a dehazing method for satellite images based on the dark channel prior and guided filter. The method is shown to effectively remove the haze and improve the visual quality of the images.

[14] Image dehazing seeks to quantify the amount of picture data lost as a result of fog, haze, and smoke in the scene at the time of capture. In image applications and consumer photography, enhancement is a necessary duty since degradation results in a loss of contrast and colour information. This paper use simulated and actual photos to show how the dehazing model impacts colour information.

[15]To eliminate haze from a single input image, this paper offer a straightforward yet efficient image prior dark channel prior in their study. A type of statistics of the haze free outdoor photographs may be found in the dark channel earlier. Its foundation is a crucial finding: most local patches in haze free outdoor photos contain some pixels with extremely low brightness in at least one colour channel. By combining this prior with the haze imaging model, they are able to directly calculate the haze's thickness and recover a clear, haze free picture. Results on a range of photographs of outdoor haze show how effective the suggested prior is.

A. Equations

$$I(x) = J(x)t(x)+A(1-t(x))$$

Here I(x) is hazed image ,which can be represented as a combination of haze recovered image and haze particles.
J(x) is the image without haze particles.
t(x) is transmission map
A is atmospheric light estimation.

III. METHODOLOGY

The methodology may be broken down into two steps:

1) *Image Dehazing*
2) *Pollution Estimation*

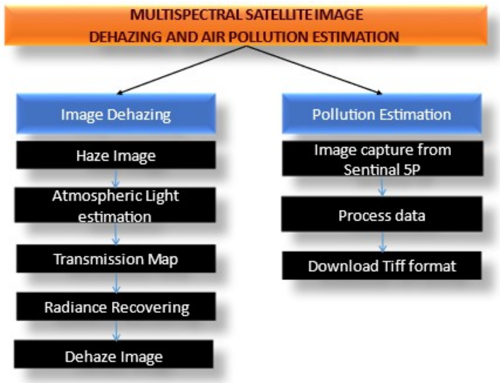

Fig 1.2: Flow of the project

3.1) Image Dehazing:

To carry out this phase, we employ a statistical procedure known as the dark-channel prior technique.

In DCP algorithm, we first calculate the atmospheric light from the haze im-age. Then, the transmission map is built after that. The constructed transmission now has to be refined, therefore it will go through this procedure to offer a refined transmission map, which will then be followed by recovering the radiance in the intermediate picture to create the dehazed image.

3.2) Pollution Estimation:

- Nitrogen dioxide (No2) pollution levels can be estimated using a variety of techniques, including air quality monitoring stations, satellite remote sensing, or modelling.

- Ground-based sensors known as air quality monitoring stations measure the amount of No2 in the air at specified sites. Although they are confined to the locations where they are deployed, they precise and dependable measurements.

- To estimate No2 levels using air quality moni stations, one can use the following steps:

  1.Identify the air quality monitoring stations area of interest.

  2.Obtain the No2 measurements from each stati

  3.Calculate the average No2 concentration fo station over a specific time period (e.g., weekly, monthly).

  Combine the station-level data to estimate the a No2 concentration for the entire area of interest.

  - Pollution estimation is providec analyzing the NO2 concentration i satellite images using remote s techniques such as the Differential C Absorption Spectroscopy (DOAS) m The NO2 concentration is estimat analyzing the absorption of sunlight ... UV-VIS range. The estimated NO2 concentration is then compared with the ground-based air quality station data to evaluate the accuracy of the remote sensing measurements.

- The color fidelity can be improved by using image processing techniques such as image dehazing, which removes the atmospheric haze and enhances the color and contrast of the satellite images. The Dark Channel Prior (DCP) algorithm is a widely used method for image dehazing, which estimates the scene transmission and removes the haze by subtracting it from the original image.

- The NO2 level in the atmosphere can be found by extracting the NO2 concentration from the satellite images using remote sensing techniques such as the DOAS method. The estimated NO2 concentration is then converted into NO2 level in the atmosphere using the molar mass of NO2 and the vertical column density of NO2. The NO2 level in the atmosphere can be used to estimate the air quality and pollution levels in a region.

IV. PROPOSED SYSTEM

Dark-Channel-Prior

A popular image dehazing method called DCP (Dark Channel Prior) uses the statistical characteristics of the dark channel in hazy photos to its advantage.

- Effective image processing to give improved image in terms of visual quality
- It is a kind of statistics of outdoor haze free images.
- Its is based on a key observation. Usually many local patches in the images contains few pixels, which have very low intensity in minimum of one channel.

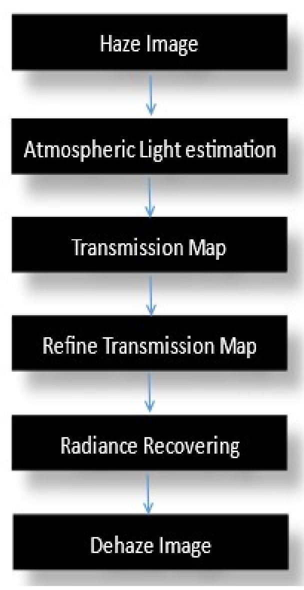

Fig1.3 Flow Chart of Image Dehazing

The steps for performing image dehazing with DCP are as follows:

- **Create the dark channel**: A 2D picture whose pixel values represent the lowest intensity in a local window around each pixel is the dark channel of an image. A box filter can be effectively used to compute this.
- **Estimate the atmospheric light**: The atmospheric light is a vector that represents the radiance of the brightest pixel in the hazy image. It can be estimated using the top 0.1% brightest pixels in the dark channel.
- **Compute the transmission**: The transmission of an image is a 2D image whose pixel values represent the amount of haze at each pixel. It can be estimated using the following equation: $t(x) = 1 - w * \min(R, G, B) / A$, where w is a weighting factor, R, G, and B are the color channels of the image, and A is the atmospheric light.
- **Perform soft matting**: Soft matting is a technique that smooths the transmission map to reduce artifacts. This can be done using a guided filter.
- **Compute the dehazed image**: The dehazed image can be computed using the following equation:

  $J(x) = (I(x) - A) / \max(t(x), t0) + A$, where I(x) is the input hazy image, t(x) is the estimated transmission, t0 is a small constant to avoid division by zero, and A is the estimated atmospheric light.

Dark Channel Prior (DCP) is an image enhancement technique that is widely used in computer vision and image processing. The main benefit of using DCP is that it is a simple and effective method for removing haze or fog from images. Here are some of the advantages of using DCP over other methods:

Simplicity: DCP is a relatively simple algorithm that is easy to implement. It does not require any complex mathematical operations or specialized hardware, making it an accessible method for both researchers and practitioners.

Fast processing: DCP is a fast algorithm that can process large images in real time. This makes it suitable for use in applications that require quick processing times, such as autonomous vehicles or surveillance systems.

High-quality results: DCP produces high quality results with minimal artifacts. It effectively removes haze from images while preserving important image features, such as edges and textures.

Robustness: DCP is a robust algorithm that can handle a variety of image types and conditions. It works well with both color and grayscale images and is effective in both indoor and outdoor environments.

No prior knowledge required: DCP does not require any prior knowledge of the scene or the camera parameters. It can be applied to any image without the need for calibration or manual adjustments.

Overall, the simplicity, speed, and high quality results of DCP make it a popular choice for image enhancement in a variety of applications.

Pollution Estimation:

- **Collect data:**
  - Obtain No2 raster file from Sentinel-5P satellite using Google Earth Engine and download as a TIFF file.
  - Using DCP for enhancing and sharpening the satellite images
- **Preprocess data:**
  - Load the raster file into the Python environment using the Rasterio library.
  - Extract the No2 data from the raster file.
  - Use the SNAP software to visualize the No2 data using a color spectrum to identify areas with high N2 concentrations.
  - Load the CSV file containing the latitude and longitude coordinates for Indian cities.
- **Process data:**
  - Loop through the CSV file to extract the latitude and longitude coordinates for each city.
  - Use the Rasterio library to find the corresponding row and column indices in the No2 raster file for each city.
  - Extract the No2 pixel value for each city from the raster file.
  - Calculate the No2 concentration in $\mu g/m^3$ using the formula: No2_concentration = (pixel_value * M) / V, where M is the molar mass of No2 in g/mol and V is the vertical column density of No2 in mol/m2.

  Print the results for each city.

- **Validate data**:
  - Combine the calculated No2 concentrations with known No2 concentration data for the same cities.
  - Use the results of the statistical analysis to assess the accuracy of the No2 concentrations calculated using the satellite data.

V. Experimental Results:

Dehazing results:

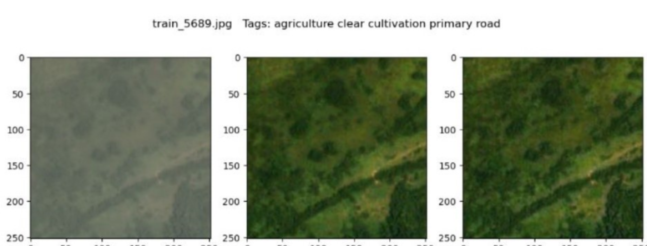

Fig.3 : Dehazing of an image containing agriculture and a primary road

(Above image shows the results generated using DCP algorithm to remove haze and other unwanted particles from the image. The first image shows the dehazed image and the last image is the corresponding dehazed image)

Estimation of Nitrogen oxide :

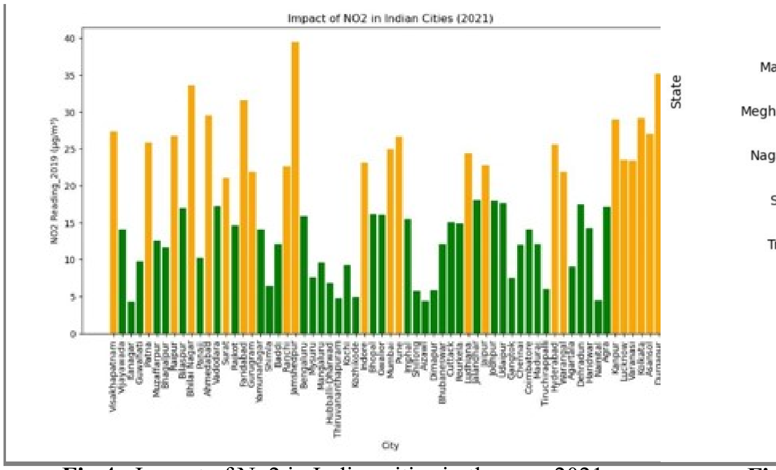

Fig.4 : Impact of No2 in Indian cities in the year 2021

(The plot depicts the nitrogen oxides levels in various cities for the year 2021.The x-coordinates represent cities and y-coordinates represent No2 reading ranging from 0 to 40 µg/m3)

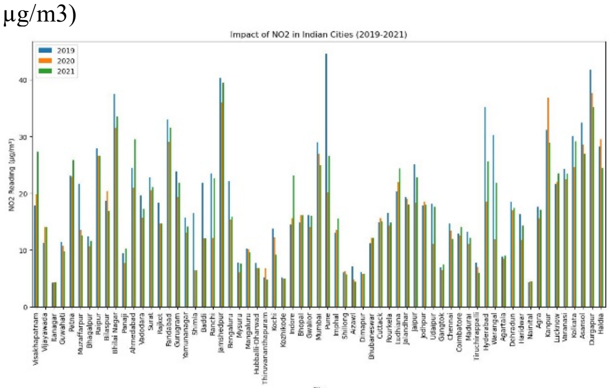

Fig 5. : Impact of No2 in Indian cities combined from the year 2019 to 2021

(The bar plot shows the concentrations of nitrogen in the different cities from the year 2019 to 2021.Pune has improved in the terms of pollution control , while the Visakhapatnam worsen over the years)

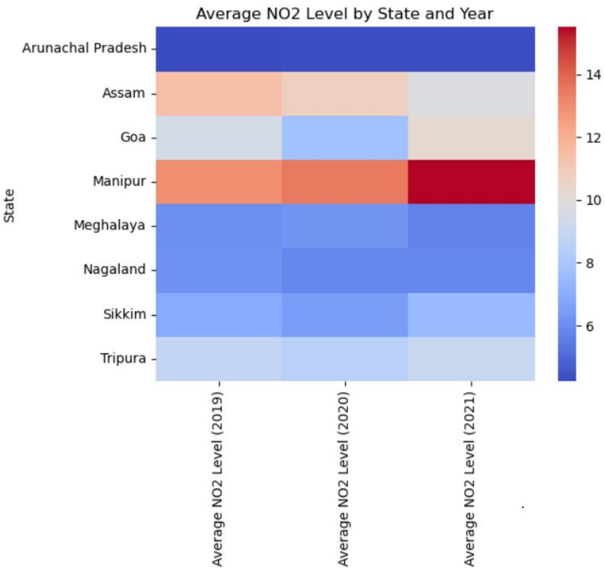

Fig.6. Average No2 level by state and year.

(Andhra Pradesh continued to be most polluted state than any other state)

City	NO2 Reading_2019 (µg/m³)
Pune	44.59612918
Durgapur	41.76118494
Jamshedpur	40.38599279
Bhilai Nagar	37.5063499
Hyderabad	35.16364659
Faridabad	32.97632586
Asansol	32.48180214
Kanpur	31.17096637
Warangal	30.30816807
Kolkata	30.13790922

City	NO2 Reading_2021 (µg/m³)
Jamshedpur	39.50281803
Durgapur	35.18819976
Bhilai Nagar	33.52375979
Faridabad	31.60051471
Ahmedabad	29.49158315
Kolkata	29.15759123
Kanpur	28.92341746
Visakhapatnam	27.33148919
Asansol	27.00796278
Raipur	26.67608518

Fig.7: Top 10 Cities by No2 Levels in year 2019 and 2021

City	NO2 Reading_2019 (µg/m³)
Itanagar	4.238407384
Nainital	4.296494171
Kozhikode	5.13884608
Thiruvananthapuram	5.191062848
Shillong	6.009031089
Dimapur	6.125036488
Gangtok	6.880493035
Aizawl	7.122264573
Hubballi-Dharwad	7.680780325
Tiruchirappalli	7.774439923

City	NO2 Reading_2021 (µg/m³)
Agartala	9.002321986
Agra	17.11908056
Ahmedabad	29.49158315
Aizawl	4.355136823
Asansol	27.00796278
Baddi	12.05839113
Bengaluru	15.84508156
Bhagalpur	11.64886594
Bhilai Nagar	33.52375979
Bhopal	16.09614676

Fig.8: Bottom 10 Cities by No2 Levels in year 2019 and 2021

VI. Future Scope and Conclusion

The project can be extended to include other methods for dehazing satellite images, such as multi-scale Retinex and guided filter, and compare their performance with DCP. The No2 detection can be further refined by incorporating more advanced models for atmospheric correction and accounting for the effect of other atmospheric gases.

The project can be applied to other regions and time periods to investigate the spatial and temporal variations of No2 concentration and their relation to environmental and human activities. The project can be combined with other remote sensing data, such as meteorological data and land use data, to provide a comprehensive analysis of the atmospheric and environmental conditions in the given region.

Conclusion

In this project, we have explored the techniques for dehazing satellite images and detecting No2 using sentinel satellite images and air quality station data. We have implemented the dark channel prior method to remove the haze from the satellite images and enhance and sharpen their visual quality. We have also used spectral analysis to detect the absorption of No2 in the atmosphere and the ground level and give a whole value to its concentration in the region of India.

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