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Dehazing of Multispectral Satellite Images

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Abstract: Dehazing multispectral satellite images is a crucial remote sensing activity since it raises the calibre and precision of satellite images. This research paper presents a comparative analysis of two approaches, namely histogram equalization and an algorithm that combines boundary constraint and contextual regularization methods for efficient dehazing of multispectral images. The algorithms successfully eliminates haze from multispectral satellite images, while preserving their features and structural integrity. Experimental results demonstrate that the latter approach outperforms the other dehazing algorithm in terms of both visual quality and quantitative measurements.
Keywords: Boundary Constraints, Contextual regularisation, Histogram Equalization, Transmission map estimation, Multispectral images

I. INTRODUCTION

Images of the surface of the Earth that are taken by sensors onboard satellites and contain information from several electromagnetic spectrum bands are known as multispectral satellite images. Applications for these photos include environmental monitoring, disaster management, urban planning, and the study of natural resources.

Using sensors intended to detect radiation at particular wavelengths, from the ultraviolet to the thermal infrared, multispectral satellite photos are taken. These sensors may gather data in several bands and provide details about the make-up, structure, and state of the Earth's surface, including things like vegetation cover, land usage, and water bodies.

The ability of multispectral satellite photos to regularly offer information about vast areas of the Earth's surface is one of their main advantages. While satellites in geostationary orbit can continuously monitor a particular area, satellites in low-Earth orbit can take pictures of the entire world on a daily or weekly basis.

As the Earth's ecosystem changes over time, multispectral satellite photos are crucial for tracking such changes. Researchers can follow changes in land use, vegetation cover, and other aspects by comparing photos taken at various times, and they can also spot trends and patterns that might be a sign of environmental change. Governments, research institutions, and commercial companies are just a few of the many industries and organizations that use multispectral satellite imagery as a significant resource for understanding and managing Earth's resources.

Multiple bands or channels that record data at various electromagnetic spectrum wavelengths make up multispectral satellite photos. Depending on the sensor used to collect the data, the amount and types of bands contained in a multispectral image may vary, but some typical examples of bands include:

1) *Blue:* This band, which typically operates between 450 and 500 nanometers in the blue region of the visible spectrum, collects data that can be used to identify water bodies and differentiate between different vegetation types.
2) *Green:* This band collects information in the visible spectrum's green region (often between 500 and 570 nanometers), which is important for determining the amount of chlorophyll in vegetation and for monitoring vegetation health.
3) *Red:* This band, which captures information in the visible spectrum's red region (often between 620 and 750 nanometers), is frequently employed for mapping vegetation and classifying land cover.
4) *Near-infrared (NIR):* This band collects data in the electromagnetic spectrum's near-infrared range (often between 750 and 1400 nanometers), which is important for determining vegetation cover, plant health, and soil moisture.
5) *Shortwave Infrared (SWIR):* This band can be used for mineral identification and mapping. It collects data in the shortwave infrared area of the electromagnetic spectrum, which is typically between 1400 and 2500 nanometers.
6) *Thermal Infrared (TIR):* This band collects information in the thermal infrared portion of the electromagnetic spectrum, which is typically between 8000 and 14000 nanometers in wavelength. It is used to monitor temperature changes on the Earth's surface, such as those caused by volcanic eruptions and wildfires.

In general, the bands found in multispectral satellite images are useful for a variety of applications, including mapping of land use and land cover, vegetation study, and mineral exploitation. These bands also provide vital information about the composition and state of the Earth's surface.

A pure Python package called Spectral Python (SPy) is used to handle hyperspectral image data. It offers tools for interpreting, displaying, modifying, and categorizing hyperspectral data. Both Python scripts and the Python command prompt allow for interactive use of it. SPy is MIT-licensed software that is available for free. In order to improve the quality and clarity of satellite photos, a critical operation in remote sensing called multispectral satellite image dehazing entails clearing the atmosphere from the images. The scattering and absorption of light by air molecules, which results in atmospheric haze, lowers the visibility and contrast of objects in the image and makes it challenging to extract usable information. Information from more than three spectral bands, typically from the ultraviolet through the infrared spectrum, can be found in multispectral satellite photos. These photos capture more details about the target being scanned, such as the condition of the flora, the amount of minerals present, or the distribution of temperature. Therefore, in remote sensing applications like agriculture, forestry, and environmental monitoring, dehazing multispectral satellite images is essential. For multispectral satellite images, a number of dehazing methods, including histogram equalization, atmospheric modeling, and machine learning-based approaches, have been proposed. Typically, these methods entail estimating the transmission map, which defines the amount of air haze in each pixel, and then enhancing the image with this knowledge. There are numerous uses for multispectral satellite image dehazing in remote sensing, including in agriculture, urban planning, and environmental monitoring. In many different domains, greater analysis and decision-making can result from improving the quality of these images.

II. BACKGROUND STUDY

Various methods have been developed to address the issue of haze removal in images. Meng et al. [1] proposed an efficient regularization technique for removing atmospheric haze. Makarau et al. [2] introduced an empirical and automatic method for detecting and removing inhomogeneous haze in satellite images.

Another approach, Virtual Cloud Point (VCP) based on Advanced Haze Optimized Transformation (AHOT), was presented by [3]. He et al. [4] proposed a simple yet effective method for haze removal using the dark channel prior. The challenges associated with haze in remote sensing data captured by satellites were discussed in [5], which also proposed a haze removal method combining the dark channel prior with atmospheric light estimation[6]. Zhang and Wang [7] introduced a novel framework called dynamic collaborative inference learning (DCIL) for restoring real surface information.

Xu et al. [8] addressed haze degradation in remote sensing images caused by different atmospheric conditions. Lin and Wang [9] proposed a fast dehazing method using a guided filter with a joint bilateral scheme for image and video processing. Dharejo et al. [10] presented a combined approach using the dark channel prior, piecewise linear transformation, and contrast-limited adaptive histogram equalization technique for haze removal.

III.PROPOSED METHODOLOGY

With the use of histogram equalization, an algorithm that combines boundary constraint and contextual regularisation techniques, the suggested work attempts to create an effective and efficient solution for dehazing satellite images. The flow diagram of the methodology is depicted in Figure 1.

A. Histogram Equalization Algorithm:

Histogram equalization is a method for changing an image's intensity distribution to change the contrast of the picture. In order to disperse the intensity values across the entire range of values, it redistributes the pixel values in the image. The algorithm comprises the following steps:

1) *Calculate an image's normalized cumulative histogram*: The normalized cumulative histogram h_c(i), for a given grayscale image of size MxN and L intensity levels, can be calculated as follows:

$$h\_c(i) = (\text{number of pixels with intensity} = i) / (\text{total number of pixels in the image}),$$

where the number of pixels with intensity = i is the cumulative sum of the histogram from intensity 0 to i, and the total number of pixels in the image is M*N.

2) *Create an intensity-mapping lookup table*: After histogram equalization, an intensity-mapping lookup table is used to map the input image's pixel values to new values in the output image. It is calculated using the input image's normalized cumulative histogram. The general formula for calculating the intensity-mapping lookup table is:

$$\text{mapped\_pixel\_value}(i) = (L-1)*\text{normalized\_cumulative\_histogram}(i),$$

where L is the standard value for an 8-bit unsigned integer representation of pixel intensity, which is 256.

3) *Using the lookup table, change the original image's pixel intensity:* The original image's pixel intensity can be changed to increase contrast using the intensity-mapping lookup table. The lookup table's general formula for converting pixel intensity is:

new pixel intensity= LT[Original pixel intensity].

Where LT is the intensity-mapping lookup table. According to the formula, each pixel in the original image has its intensity value looked up in the lookup table for intensity mapping, and then a new intensity value is assigned to that pixel in the transformed image.

B. Efficient Image Dehazing with Boundary Constraint and Contextual Regularisation Algorithm:

An image dehazing algorithm called Efficient Image Dehazing with Boundary Constraint and Contextual Regularisation tries to eliminate haze from images while retaining the scene's specifics and colors.

The following steps make up the algorithm:

1) *Dark Channel Prior (DCP)*: The blurry image's atmospheric light and transmission map are estimated using DCP. The dark channel of the hazy image, which is the minimum intensity value in a particular region, is initially calculated by the method. The image with no haze, which is blurred by air scattering, is represented by the black channel. The haze-free image is probably made up of the pixels in the dark channel with the lowest intensity. The maximum intensity value among these pixels is thought to be the atmospheric light. The transmission map is then calculated using the following equation once the ambient light has been estimated.
2) *Transmission map:* A transmission map is a map that shows how much haze or fog is present in each pixel of the input image in Efficient Image Dehazing with Boundary Constraint and Contextual Regularisation. The atmospheric veil is assumed to be the primary cause of the minimum intensity value of all the color channels in a local area of the image when it is assessed using the dark channel prior approach.
3) *Atmospheric Light Estimation:* The amount of light that is scattered by the scene's atmospheric elements is referred to as atmospheric light in the context of image dehazing. Due to the fact that it affects the overall brightness and contrast of the final image, it is a crucial parameter for dehazing algorithms. The top 0.1% brightest pixels in the dark channel of the input hazy image are used to estimate the ambient light in Efficient Image Dehazing with Boundary Constraint and Contextual Regularisation.

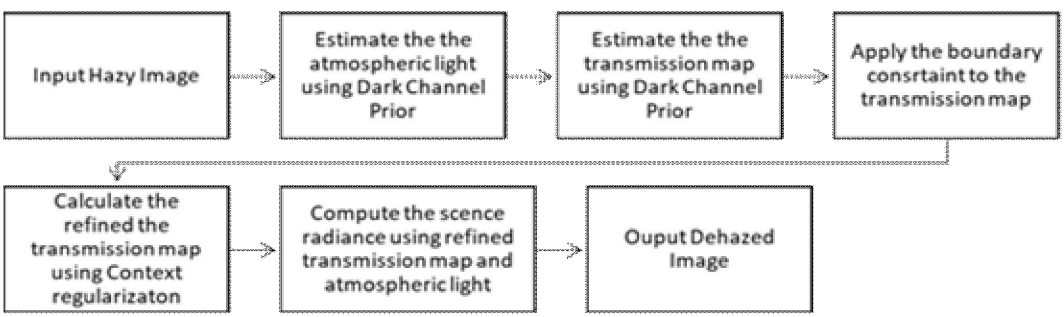

Fig. 1 Block Diagram Efficient Image Dehazing with Boundary Constraint and Contextual Regularisation Algorithm

4) *Boundary Constraint:* This is how the boundary constraint term is defined: Let H(x) be a binary function that determines whether or not a pixel x is on the image's edge. The boundary constraint term B(I) is therefore specified as:

B(I) = [x,y] [H(x,y) * (I(x,y) - L)]

where I(x,y) represents the pixel's intensity value in the blurry image. I, L stands for estimated ambient light, [x, y] for the coordinate of a pixel, and for the collection of all picture pixel coordinates. In order to urge the algorithm to maintain the boundaries of objects in the image and avoid over-smoothing, the boundary constraint term is utilised. It only impacts the pixels on the boundary by weighting the constraint term with H(x,y), leaving the inside pixels unaffected.

5) *Contextual Regularisation:* To further enhance the dehazing outcome, contextual regularisation is applied. The main idea is to add a regularisation term that encourages close pixels to have comparable transmission values, hence enforcing smoothness in the transmission map.This is how the phrase "contextual regularisation" is defined:

R(t) = lambda * sum_i (w_ij * |t_i - t_j| * sum_i)) where w_ij is the contextual weight between pixels i and j, t is the transmission map, and lambda is a parameter that regulates the regularisation's strength.

w_ij = exp(-beta * ||p_i - p_j||2) is the definition of the contextual weight.

where p_i and p_j are the color values of pixels i and j, respectively, and beta determines how heavily the context is weighted.

The final objective function that is optimized to obtain the transmission map is

E(t) = -log(t) + lambda * R(t)

IV. DESIGN AND IMPLEMENTATION

This section represents the environmental set up used for the implementation, data set used and exploratory analysis of the input data set.

A. Environmental Setup

Python modules are used for the implementation of the proposed algorithms. The dataset was downloaded from https://vedas.sac.gov.in/en/sih2022.html which was released during Smart India Hackathon 2022. The following figure 2 depicts few sample images. In addition, a multispectral image with 220 bands was downloaded from this site and different bands where extracted using …. library.

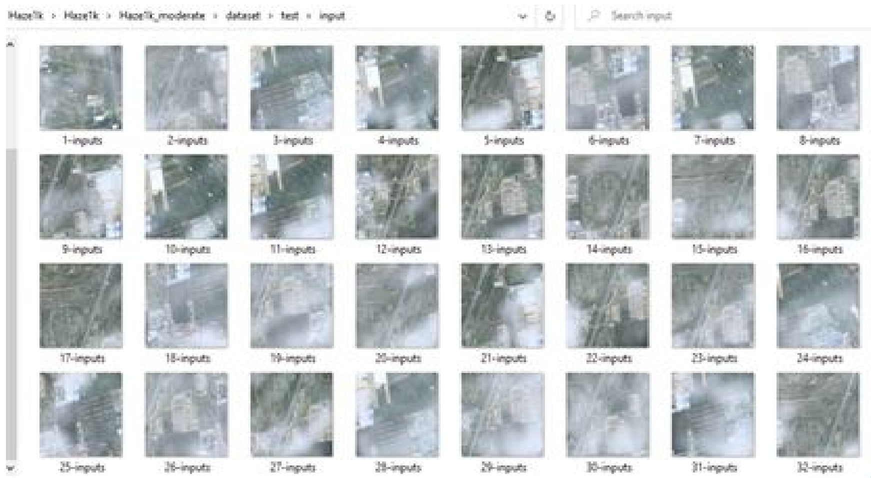

Fig. 2 Sample Images from the Dataset

B. Implementation Results

The following figure 3 depicts the result of Histogram equalization procedure on the selected input image.

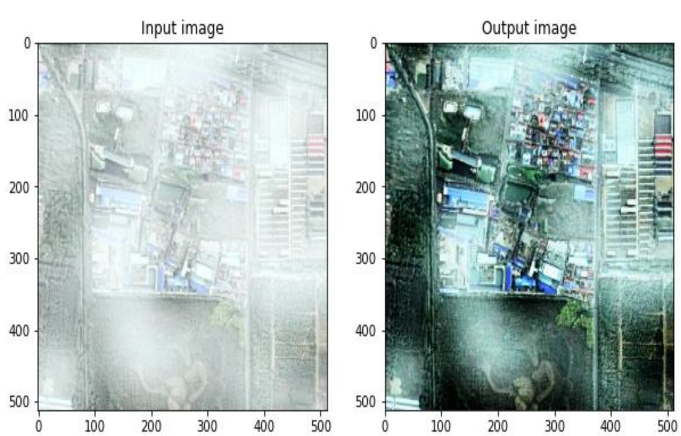

Fig. 3 The input image and Histogram Equalized Image

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The following figure 4 depicts the transmission map obtained and the resultant dehazed image after applying boundary constraint and contextual regularisation techniques.

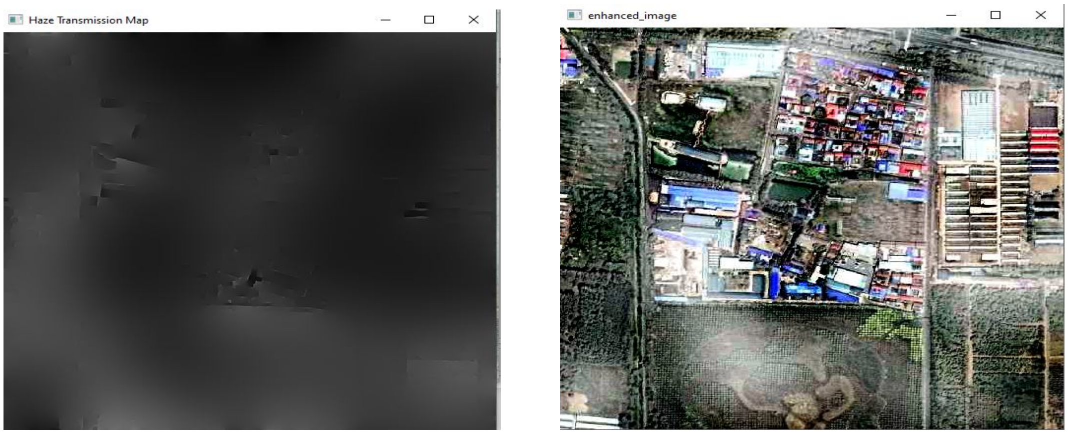

Fig. 4 Transmission map and the dehazed image after applying boundary constraint and contextual regularisation

C. Result Analysis

To assess the performance of histogram equalization, effective image dehazing with boundary constraint, and contextual regularization in comparison to the target image, metrics such as Peak-Signal Noise Ratio (PSNR) and Mean Square Error (MSE) are computed. A lower MSE value and higher PSNR and SSIM values indicate better image dehazing performance. By comparing these values, it is observed that the Boundary constraint and contextual regularisation algorithm exhibits a lower MSE (100) and a higher PSNR (28) compared to the Histogram Equalization, implying superior performance. The corresponding results are presented in Table 1.

TABLE I
PERFORMANCE ANALYSIS OF THE ALGORITHMS

Algorithms	PSNR	MSE
Histogram Equalization	15.32	1909.07
Boundary constraint and contextual regularisation	28.10	100.62

V. CONCLUSIONS

This papers presents a comparative of analysis of two popular approaches to efficient dehazing of multi-spectral images with border constraints, contextual regularisation, and histogram equalization. The results show that, when compared to histogram equalization, dehazing with border constraint and contextual regularisation, has lower MSE and higher PSNR values. Future studies can be conducted to improve the effectiveness of multispectral image dehazing tasks using both histogram equalization and efficient image dehazing with boundary constraint and contextual regularisation. The scope of this study can also be expanded to include more datasets in order to evaluate how well these algorithms perform in various scenarios.

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