Improved Homomorphic Filtering for Thin Cloud Removal

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Abstract **- Thin cloud is opaque, and a photo of the area covered by thin cloud contains the component of troposphere (thin cloud effect) and the ground reflection. Using Homomorphic Filtering (HF) to remove thin cloud is a popular method occupation as the terrestrial is simply contaminated by noisy effect which is usually randomly occurring. This research presents an attempt to explain how an improved HF can be used for thin cloud removal in satellite remote imagery. This is realized by considering the images taken for ground object as low frequency components and then attempt to find best high-pass for them. Here, optimal cut-off frequencies are determined on a semi-automatic maneuver and optimality is tested based on the best tuning for removing the effect of thin cloud on ground scene. The proposed method has been implemented in MATLAB environment and tested on various images from different locations in order to proof its validity. The results prove that adequate and viable thin cloud removal is achieved and noticeable clear remote sensing images are obtained. Further, the proposed method's performance was benchmarked with a recent similar work. According to benchmarking results, the proposed method outperform its counterpart in both success and failure rates which verifies its validity.**

Keywords: Improved Homomorphic Filtering, Cut-off frequency, High-pass filtering, Homomorphic Filtering, Thin Cloud Removal

1. INTRODUCTION

Generally clouds are considered as obstruction for land-surface observation and they cause a blur or less in the regional information. Thin clouds are considered physically not opaque, and images of ground objects that are partially/fully affected by thin clouds contain the components of atmosphere (thin cloud effect) and the terrestrial scene. For this reason, thin cloud elimination is sensitive and cumbersome procedure as terrestrial information can be easily affected when applying a straightforward elimination of noise generated by thin cloud existence. This procedure is a very challenging task since images of part covered by thin clouds do not only contain the cloud information but also the ground features, including the eradiation and structure [1]. The procedure of clouds effects removal has been proposed and followed in order to reduce the noise on satellite imagery and remote sensing; especially for high-quality imagery applications [1-3]. This procedure has been thoroughly investigated and widely applied; yet the application may vary based on the followed theoretical basis so may the results. Regardless of the used approach and theoretical considerations, thin clouds removal highly improves the outcomes of imagery and remote sensing techniques. Various thin clouds removal methods have been proposed. These methods can be categorized as; filtering methods [4-8], histogram matching [10], dark pixels elimination [11, 16]; and multi-image based methods [12, 13].

Thin cloud removal methods have been existing for a relatively long time where recorded proposals root back to 1970s. Nevertheless, a direct application to thin cloud removal was presented in the work of Mitchell in 1976 [9]. Mitchell had proposed a filtering idea in his work that copes with thin clouds. He developed a model for cloud distortion, simulated a contaminated image and applied homomorphic filtering. The developed model was able to partially remove the noise effects and reconstruct a visible image. Although this work presented a successful attempt, the main issue is the lack of real data use as well as a feasible refinement technique. The development further progressed in this field and a new method was developed by Chanda and Majumder in 1991 [15]. In their work, they developed an iterative algorithm that copes with the thin cloud distortion on LANDSAT imagery. The algorithm is essentially based on number of parameters that consider the physical situation along with tapered-shape low-pass filter to remove the influence of thin cloud while enhance it remotely captured images. In an effort to create a more robust and extensive study, in 1996 Richter proposed and developed an adaptive spatial fast atmospheric algorithm for correcting remote satellite images. In this work, contaminated images were purified using a look-up table that contains atmospheric correction functions which need an interactive user identification to highlight the contaminated pixels in order to be removed by the proposed sophisticated algorithm [16]. The main disadvantage of this study is that user interaction is needed as a part of the process; also image quality is totally dependent on with the information provided in the look-up table that could be invalidly obtain at certain points in the calculation. Another attempt was presented in work of Zhang et al. where a quantitatively tested optimized image transformation for radiometry compensation of visible band to produce and enhanced view for satellite images affected by have or thin clouds [18]. The method is based on the correlation between clear scenes and contaminated parts in order to create a purification function to produce an acceptable elimination of haze effect on terrestrial view. The attempt had produced considerable results in combating haze contaminations on satellite imagery.

However, the method assumes that the view should have various clear regions in order to create the needed compensation which is impractical in usual circumstances. Cai et al. proposed a self-adaptive homomorphic filtering method for thin cloud removal purposes. The method applied Laser Interferometer Space Antenna (LISA) to extract regional cloudy element and then based on the thickness of the regional cloud, cutoff frequencies are adjusted to optimize the performance of filtering process which improves the overall process [19]. The success of Cai et al. study had led Wu et al. to conduct a thin cloud removal based on improved homomorphism filtering procedure. In their study, they attempted to enhance the quality of satellite high resolution imaging by minimizing the distortion resulted from homomorphic filtering technique. Based on qualitative and quantitative evaluation, their results showed a significant improvement of captured images contaminated by thin clouds. Even though the use of improved homomorphism produced better results in Wu et al.'s study, it has a lack of a thorough investigation and validation using various data types in order to define the applicability of the method and the possible ways for improvement. In the same regard, Sousa et al. attempted to apply statistical measures along with homomorphic filtering aiming to remove the influence of thin clouds and similar atmospheric phenomena. In their evaluation, they pointed out the use of high-boos filtering works best for such purposes [14]. Shen et al. presented one of the very recent developed models which conducted a classical homomorphic filtering in frequency domain in order to eliminate the effect of thin clouds on remote sensing images [1]. In their experiment, they considered thin clouds as low frequency component and the optimal cutoff frequencies were semi-automatically found for each channel except the first one producing an enhanced imagery for remote sensing applications. The proposed method produced appreciated results, especially to colored images; however, the complexity of manual tuning of first channel remains persistent and may create deterioration in the optimal performance if not carefully considered. Lv et al. proposed that the removal of thin cloud cover in visible bands is possible based on the simplified radioactive transfer equation and two assumptions. The evaluated the algorithm used a Landsat 8 sub-image of 041/036 (path/row) that was acquired in 2014 [20].

In this paper, we proposed a thin cloud removal method based on an improved HF. The main motivation of the work arises from the HF based methods are not quite successful in removing thin clouds. To this end, the input image is firstly decomposed into its color channels and each channel is processed independently. The processed channels are then combined to obtain the final image. In HF, the high pass filtering is applied to the image which is transferred into the logarithmic domain. The improved HF is obtained by adding an offset and a scaling factor to construct a Gaussian high pass filter. Thus, an improved filter is constructed which amplifies the high frequency components more than the low-frequency components. The improved HF is applied on various satellite images which contain thin clouds. The obtained results are evaluated visually and compared with the traditional HF results. Visual evaluations show that the improved HF yields sharper and better contrast images than HF method.

The paper is organized as follows; in the next section; we give some brief introductions to related theories such as thin cloud model and HF. In section 3, the proposed method is presented. Experimental works, results and discussions are given in Section 4. We finally conclude the paper in Section 5.

2. THEORETICAL FRAMEWORK

2.1. Thin Cloud Modeling

Basically, due to the attenuation, scattering, and reflection resulted from the thin cloud, the distorted image is represented as in Eq. (1) [17, 21]:

$$I(x,y) = aLr(x,y)t(x,y) + L(1 - t(x,y)) \quad (1)$$

where $I(x,y)$ is the intensity of the modelled image, a is the scaling effect of attenuation resulted from thin clouds, L is the solar radiation intensity, $r(x,y)$ and $t(x,y)$ are representing the albedos of both ground imagery object and thin cloud component, respectively. Essentially, in order to remove the effect of thin cloud on ground image component, the second part of Eq. (1) should be removed.

2.2. Homomorphic Filtering (HF)

HF is one of the known methods in the practical applications, and thin cloud image filtering as illustrated in Fig. 1. As can be seen in Fig. 1, the input intensity image is firstly transferred into logarithmic domain because conversion of the multiplication to addition is needed. The log-transformed image is then filtered by a high-pass filter. Finally the high-pass filtered image is converted to the intensity domain by an exponential operation.

Fig.1 The block diagram of HF

The HF works based on separating the components with the low spatial frequency from the reflectance which is considered as high frequency using Fourier-based high-pass filtering as shown in Fig. 2. In Fig. 2, the F and F^{-1} shows the Fourier and inverse Fourier transforms, respectively. $H(u,v)$ shows the frequency domain high-pass filter. High-pass filters works based passing frequency spectra higher than certain cut-off frequency and block all other components that are less than the cut-off frequency. The signal fed into a high-pass filter can be composite of additive signals, thus, allowing simple applications as low-frequency noise removal. However, in the case of thin cloud illumination reflection problem, low-frequency illumination is doubled, instead added, to the high-frequency reflectance.

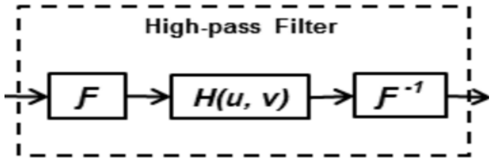

Fig. 2 The block diagram of high-pass filter

3. PROPOSED METHOD

In this paper, a straightforward thin cloud removal method is proposed. The proposed method improves the traditional HF method. The flowchart of the proposed methodology is shown in Fig. 3. As can be seen in Fig. 3, the proposed method consists of color channel decomposition, applying improved HF to each color channel and combining filtered color channels to obtain final image. Differently than the tradition HF, in improved HF, the frequency domain high-pass filtering is formulated as [22];

$$H_i(u,v) = \alpha + \beta H(u,v) \tag{2}$$

Where $H_i(u,v)$ shows the response of the frequency domain improved high pass filter and α and β indicates offset and scaling factor, respectively. The motivation of such improvement aims to amplify the high-frequency components more than the low-frequency components.

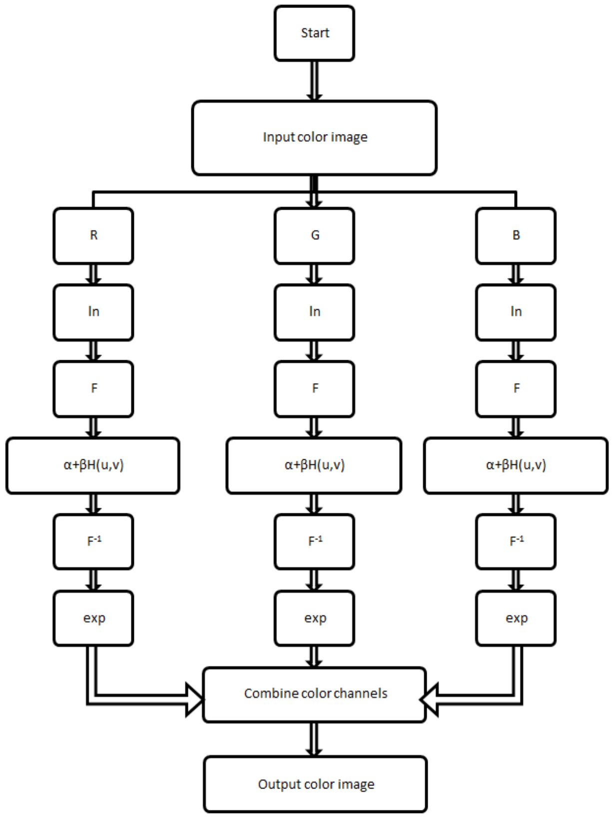

Fig.3 Block diagram of the proposed methodology

4. EXPERIMENTAL WORKS, RESULTS AND DISCUSSION

4.1. Data Collection and Procedure Description

In the experiments, a dataset of thin cloud was collected for cloud removal using improved homomorphic filtering. A total of 5 satellite image patches have been used in the experiments. These images contain a variety of thin cloud effects which exist in different frequency ranges including: low-pass and high-pass frequencies located in different areas. The dataset is used for evaluating the proposed method and the output of each stage is presented and discussed. All experiments implementation is done in MATLAB environment with a Windows operating system machine of (64-bits) and 2.53GHz processor.

4.2. Results and Discussions

The obtained results are shown in Fig. 4. The first, second and third columns of Fig. 4 shows input images, HF filtered images and improved HF filtered images, respectively. In the last column of Fig. 4, we specified the related parameters. In all experiments, we used Gaussian high-pass filter. The sigma value of Gaussian high pass filter is tuned during experiments. In addition, the alfa and beta parameters of the improved HF need to be tuned. These parameters were also adjusted during the experiments. As we visually inspect the results which are given in the first row of Fig. 4, we can see that the improved HF removed more clouds than traditional HF. In addition, the contrast of the improved HF filtered image is sharper that HF method. But it should be mentioned that there are some cloudy parts in the filtered image. Two

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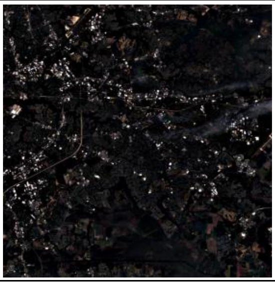
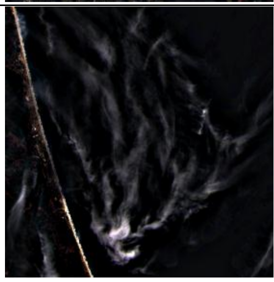
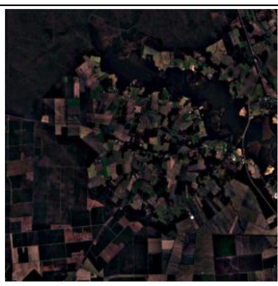
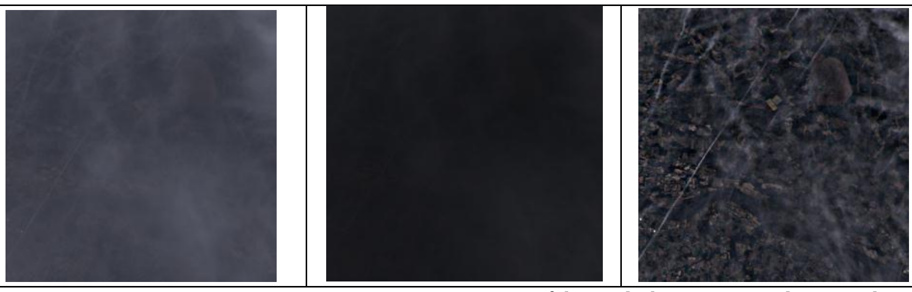
better results can also be seen in the second and fourth rows of the Fig. 4. These input images looked like that they contain a uniform haze. As shown in the second column of Fig. 4, the HF did not produced enhanced images. In addition, the thin cloud is visible in the both HF filtered images. On the other hand, improved HF produced reasonable images. Both improved HF filtered images enhanced obviously. The terrestrial structures became more visible. In the third row of Fig.4, we experimented on an image where the thin cloud is located on the water region. Similar to the previous results, HF did not obtain an enhanced output image. The image structure became darker. In addition, improved HF produced better filtered image on the terrestrial regions and failed to filter the thin clouds that were on the water regions. In the last row of the Fig. 4, we experimented on an image which has dense cloud. As it can be seen, HF failed to remove the dense cloud, but improved HF produced better result than HF. But improved HF also failed to remove the whole clouds.

As a general evaluation, the experimental works show that the improved HF is quite good in removing the thin clouds that are on the terrestrial regions. Improved HF also enhanced the contrast of the input image while tradition HF failed. It is also worth to mentioning that the improved HF is also worse to remove the thin clouds on water regions.

Input images	HF results	Improved HF results	Related parameters
			HF sig: 0.1 Improved HF sig: 10 Alpha: 0.5 Beta:10
			HF sig: 0.2 Improved HF sig: 10 Alpha: 0.5 Beta:15
			HF sig: 0.3 Improved HF sig: 10 Alpha: 0.5 Beta:20
			HF sig: 0.4 Improved HF sig: 10 Alpha: 1 Beta:20



HF sig: 0.5
Improved HF sig: 15
Alpha: 1.5
Beta:20

Fig. 4 Comparison of the results between HF and improved HF

5. CONCLUSIONS

This study proposed an effort for enhancing the quality of remote sensing satellite imagery that partly or whole covered by clouds. The aim was especially guided to thin cloud removal that contaminates satellite images and deteriorates the clarity of the imaged ground objects. Various proposed methods were thoroughly discussed and investigated. Based on these methods as well as a deep understanding of the characteristics of thin cloud and optimum removal methods, an enhanced thin cloud removal technique was proposed, presented, tested and benchmarked. The proposed method is essentially based on improved homomorphic filtering. The results were encouraging and a total of 5 images were used to determine the performance of the proposed method. In order to verify and validate the proposed method's feasibility, a benchmark steps were conducted and the proposed method was compared with traditional HF method. The proposed method's success rate surpassed the traditional HF method. The study can and should be further developed using various images based on different satellites and locations. Blurring effect can be also incorporated with a further development to enhance the overall performance of the current algorithm and it should be presented as a new direction of research. In addition, the algorithm can be also implemented by different programming language and compared in different machines in order to classify the feasibility of any further machine-based or programming based enhancement.

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