

**REPUBLIC OF TURKEY
FIRAT UNIVERSITY
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**THIN CLOUD REMOVAL USING HOMOMORPHIC
FILTERING**

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**Master's Thesis
Department: Software Engineering
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DECLARATION

I announce that this thesis "Thin Cloud Removal Using Homomorphic Filtering" is set up independent from anyone else an incomplete satisfaction of the necessities for the Master degree of Science in Software engineering.

Abdalqadir M. Jazaa SALIH
ELAZIĞ-2017



DEDICATION

To my most beloved ones, to those who gave me their time especially Prof. Dr. ABDULKADIR ŞENGÜR and my teachers in Firat University, care, help and hope, and to my beloved family, and MY WIFE, and to all friends give help.



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Abdalqadir SALIH

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ABSTRACT

THIN CLOUD REMOVAL USING HOMOMORPHIC FILTERING

Thin cloud is opaque, and a photo of the area covered by thin cloud contains the components of the troposphere (thin cloud effect) and the ground reflection of the image. Using Homomorphic Filtering (HF) to remove thin cloud is a popular method occupation as the terrestrial is simply contaminated by the noisy effect which is usually randomly occurring. This research presents an attempt to explain how an HF will be used for thin cloud removal for satellite remote imagery. This is realized by considering the images taken for a ground object as low-frequency components and then attempt to find the best high-pass frequency 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 a 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.

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

ÖZET

HOMOMORFİK FİLTRELEME İLE İNCE BULUT TEMİZLENME

İnce bulutlar opakdır ve ince bulutla kaplanmış bir alanın fotoğrafı, troposferin bileşenleri (ince bulut etkisi) ve zemin yansıma görüntüsü de fotoğrafta bulunmaktadır. İnce bulutlardan kurtulmak için, homomorfik filtreleme (HF) en yaygın yöntemlerden biridir, zemin görüntüsü genellikle rasgele meydana gelen gürültülü etki tarafından kolayca kirlenir. Bu araştırmanın amacı HF yardımıyla, uydudan çekilmiş fotoğraflardaki ince bulutların giderilmesidir. Bu durum yer üzerindeki bir cisim için düşük frekans bileşenlerle çekilmiş fotoğrafı alıp, en iyi yüksek geçiş frekansını bulma ile gerçekleştirmektedir. En uygun kesme frekansları yarı otomatik bir olarak belirlenir ve zemin görüntüsü üzerindeki ince bulut etkisini ortadan kaldırmak için en iyi parametre değerleri bulunarak test edilmektedir. İnce bulut gidermek için iki farklı algoritma (HF ve İyileştirilmiş Homomorfik Filtreleme (İHF)) kullanılmaktadır. Kullanılan yöntemler, MATLAB ortamında uygulanmış ve geçerliliğini kanıtlamak için farklı yerlerin çeşitli görüntüleri ile test edilmiştir. Testlerin sonuçları, yöntemin uygunluğunu kanıtlanmış ve bu metodu kullanarak ince bulutların giderilmesi sağlanmıştır. Yöntemlerin başarımları görsel olarak değerlendirilmiş ve yöntemlerin iyilikleri ve zayıf kaldıkları yönler yorumlanmıştır.

Anahtar Kelimeler: Kesim frekansı, Homomorfik Filtreleme, Yüksek geçiren filtreleme, İyileştirilmiş Homomorfik Filtreleme, İnce bulut giderilmesi.

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SYMBOLS AND ABBREVIATIONS

α	: Alpha
β	: Beta
ETM+	: Enhanced Thematic Mapper Plus
GBR	: Color of image
HE	: Histogram Equalization
HF	: Homomorphic Filtering
HFCR	: Proposed method
IHF	: Improved Homomorphic Filtering
MSR	: Multi-Scale Retinex Algorithm
sig	: Sigma

1. INTRODUCTION

This chapter attends a general introduction of this thesis. This introductory part includes a general overview about thin clouds removal and the visualization of possible controlling factors. It also discusses the basic terminologies and application theories which are used in the rest of the thesis, such as homomorphic filtering. Finally, the chapter presents the organization of the thesis by describing the rest of the chapters.

1.1. Overview

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/removal is a sensitive and cumbersome procedure as terrestrial information can be easily affected when applying a straightforward elimination of noise generated by thin cloud existence. Thin cloud removal is an improving procedure deployed by remote sensing and imagery technologies. This procedure is a very experimentation task since images of part covered by thin clouds do not only contain the cloud information but also the ground features, including the irradiation 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 [2, 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, investigated, developed and tested. These research attempts can be categorized based on the used thin cloud reduction or elimination technique to single image based methods such as filtering methods (mostly based homomorphic filtering) [4-9], histogram matching [11], dark pixels elimination [12, 17]; and multi-image based methods such as image reconstruction from multi-temporal satellite images [13, 14]. These methods will be thoroughly investigated in the next subsection.

Essentially, there is no absolute “best” method for thin clouds removal; rather the proposed methods and research ideas have a relative performance when compared with uncontaminated images. The main idea is producing an acceptable image quality of visualization and analysis if needed.

1.2. Literature Review

Cloud removal attempts have been existing for a relatively long time where recorded proposals root back to 1970s [15]. Nevertheless, a direct application to thin cloud removal was presented in the work of Mitchell in 1976 [10]. Mitchell had proposed in his work a filtering idea that copes with clouds (thin clouds) cover that obstructs the clear presentation of satellite imagery. He developed a model for cloud distortion, simulated a contaminated image and applied his homomorphic filtering model to purify the image with it. The results were impressive back then and the developed model was able to partially remove the noise effects and reconstruct a visible image, as shown in Figure 1.1. Although this work presented a successful attempt, the main issue is the lack of real data use as well as a feasible refinement technique.

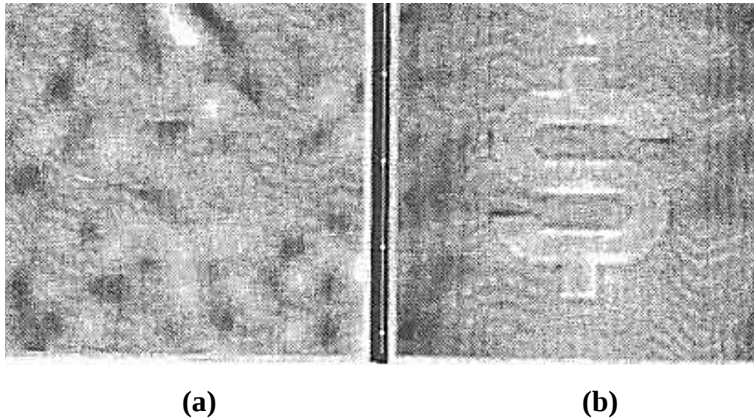


Figure 1.1. Computer simulated noisy image (a), filtered image result (b)[10]

The development further progressed in this field and a new method was developed by Chanda and Majumder in 1991. 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 Rinchter

proposed and developed an adaptive spatial fast atmospheric algorithm for correcting remote satellite images. In that 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 [17]. 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. Gao and his colleagues approached the same problem in a different manner. They proposed the use of empirical algorithm in an effort to reduce thin clouds effects on satellite imagery [18]; however, they restricted their implementation and application to cirrus only. This attempt had also addressed only two channels in the range of 1.38 and 1.24 μm for image correction and 0.66 and 1.38 μm for images taken over land. Although the algorithm had succeeded in obtaining cirrus removal in both cases, as illustrated in Figure 1.2, yet like most of empirical methods, this attempt is suffering from uncertainty issues related to original data as well as lack of robust correction method for errors introduced by cirrus transmittance factor [18].

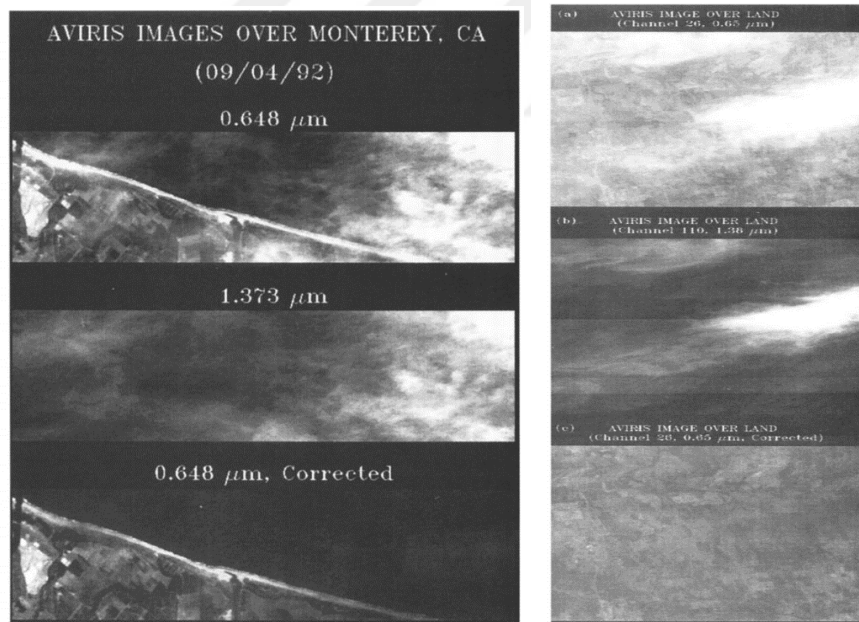


Figure 1.2. Over water surface (left) and over land surface (right): Channel 1 image (top) [18]

An extensive 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 [19]. The methods are 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, as seen in Figure 1.3, in combating haze contaminations on satellite imagery [33];

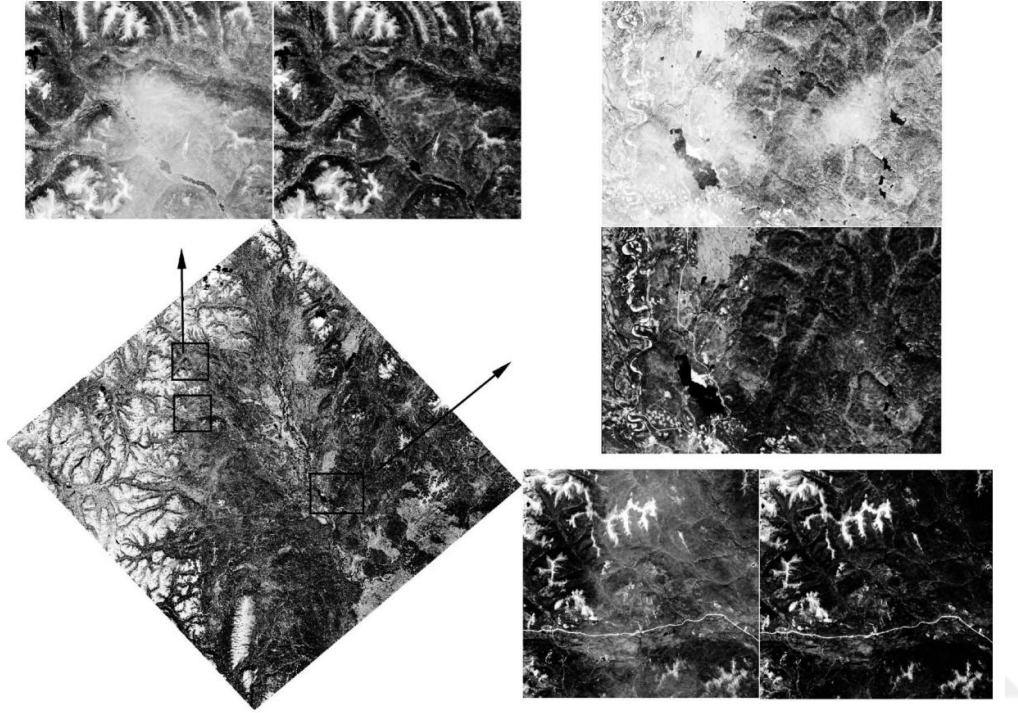


Figure 1.3. Surface recovery details based on haze optimized transformation method [19]

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. More recently, a number of studies proposed the use of enhanced advanced filtering methods to improve and refine the satellite images quality by removing thin clouds effects [1-3][8,9] [20]. These filtering techniques are based on homomorphic filtering principles, which will be discussed in details at (chapter 2) of this thesis, in order to eliminate/reduce the effects of thin clouds on terrestrial view of satellite imagery. Basically, the approach relies fully/partially on the morphology in mathematics where low and high frequencies are separated using opening/closing operation which then allows the removal of thin cloud as they are low frequency component. This method has been adopted by a number of studies as it proved its efficiency in thin cloud removal. 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 [20]. 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 [9]. They also conducted a comparative study on the performance of enhanced homomorphism filtering and homomorphism filtering, as shown in Figure 1.4. 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-boost filtering works best for such purposes [15]. 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. 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 [1].

The proposed method produced appreciated results, especially to colored images, as shown in Figure 1.5; however, the complexity of manual tuning of first channel remains persistent and may create deterioration in the optimal performance if not carefully considered.

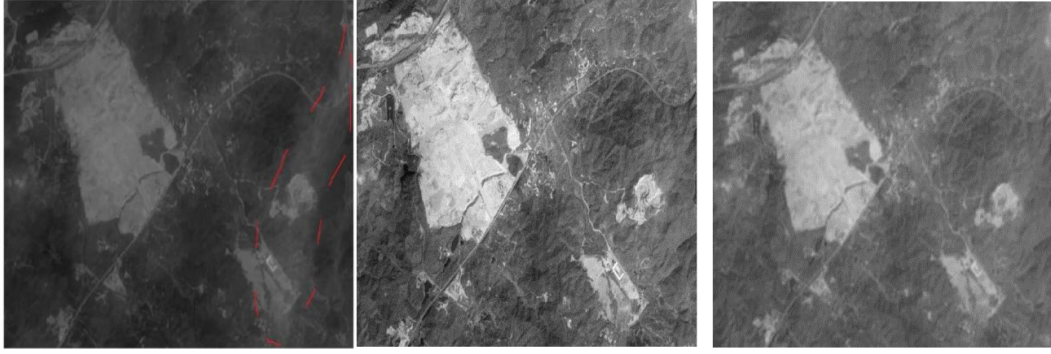


Figure 1.4. Contaminated image (left), homomorphism filtered image (middle), improved homomorphism [1]

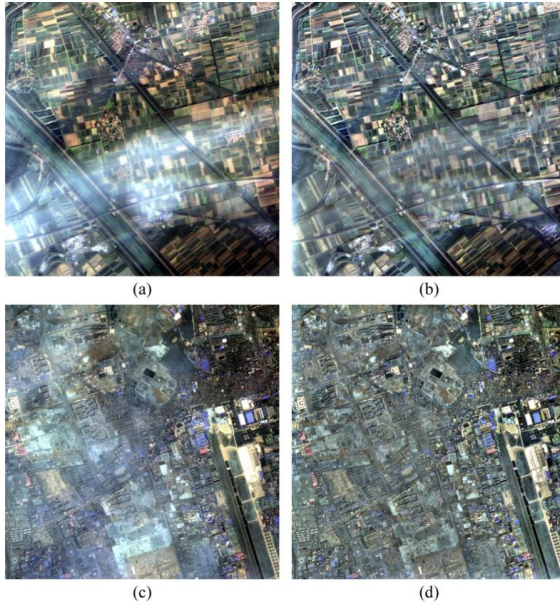


Figure 1.5. Left column presents original contaminated images and right column [14]

Specific speaking, various methods have been proposed that rely on plain atmospheric correction to alleviate the effect of thin cloud on ground images. However, these methods do need adequate information about both atmospheric properties as well as the sensor profile in order to be able to reduce/eliminate the generated attenuation. In addition, if the available information tends to be relatively inaccurate or misinterpreted, then the results will be highly deteriorated.

Chen *et al.* proposed a method for haze effect removal which can be applied for thin cloud removal system. Their method is essentially relying on pixel correction considering various controlling parameters including: signal transmission, clouds additive reflectance, as well as energy attenuation due to the clouds. The proposed method utilized a fitting

direction of cloudy pixels with the assistance of IHOT keeping in mind the end goal to spatially describing cloud for pixel revision [24]. Similarly, Meng *et al.* proposed and developed a novel approach that considers thin cloud reflectance and absorption in the process of pixel correction; here, the method approached thin cloud removal by correcting contaminated pixels via spectral analysis. The correction is obtained by deducting the effect of cloud components: member signature and cloud abundance, which is ultimately tuned based the thickness of the cloud. The main advantages of this approach are that it does not need any ground imagery reference not does it need any update for meteorological status [30]. Ming *et al.* proposed a method for thin cloud removal that supports vector value filter. The method applied decomposing of thin cloud-contaminated remote sensing images into multi-resolution sub-band coefficients. Through suppressing the low frequency coefficients, thin cloud is removed effectively and ground object information is preserved sufficiently. This method has advantage over other methods by supporting vector value filter which is referred to as a good generalization and can strongly catch singularity ability [26]. Jun *et al.* decided to approach thin cloud removal by building a thin cloud physical model that considers the unequal distribution of cloudy components. In their work, they used some sort of adjustment algorithm that blocks spots with gray scale in order to reduce the influence of dark objects. The essential process was mainly dependent on subtracting the cloudy background which is determined by the physical model. The effect of transmission was taken into the account by adaptively tuning the contrast final image color which highly reduced the influence of the transmission [31].

Some other researchers approached the problem to thin cloud effect by designing a proper filtering method. In this regard, Asharif *et al.* proposed homomorphism filtering for thin cloud removal which is considered straightforward and less complex method. Here, the homomorphism filtering was used for highlighting and extracting the spots that mostly affected by shadow (as a result of thin cloud shadowing). The focus of this method was guided towards the effects of illumination as well as reflection on the terrestrial image which dealt with separately based on the gray-level of the image components. The method employed HSV color space for analysis purposes which uses color component value (for instance dark or bright) in order to enhance the overall accuracy of the shadowed regions [28]. Chao-Hung *et al.* developed a thin cloud removal technique that produced relatively superior performance compared to similar methods. They used images recoded by Landsat-7 via Enhanced Thematic Mapper Plus (ETM+) sensor in their experimental work and

based their notion on reconstructing a clear image using prerecorded images that can be used for patch-enhancement relying on the idea of insignificant changes may happen to the ground information in a short period [22]. Although the work of Chao-Hung *et al.* produced quality results, yet the assumptions they made tend to be impractical as instantaneous ground information may be required. Zheng *et al.* investigated and proposed a method based the physical properties of thin cloud cover. The idea of their method is that in channel of the range $0.4\ \mu\text{m}$ to $1.0\ \mu\text{m}$ and $1.38\ \mu\text{m}$ there is a linear relationship between the produced reflectance. The idea succeeded at first to obtain ground information for terrestrial objects, yet it was not successful for water surfaces. They attempted to tune the used channels, and they succeeded in using $0.66\ \mu\text{m}$, $0.86\ \mu\text{m}$ and $1.38\ \mu\text{m}$ for recovering water body images beneath the thin cloud cover. The developed mode was used for testing images contaminated by think cloud effect from two main different sources to validate their results [25]. Yinqi *et al.* proposed a fog removal from single satellite imagery. The proposed method exploited the dark channel prior algorithm to improve the overall view of the ground object. The atmospheric cover is estimated at first using the dark channel period theory not by referring to the image components. They also applied a sharp low-pass filter (Guassain-based) and a sophisticated feedback refinement to the estimated atmospheric in order to remove the unwanted thin cloud or fog components that exist. They also added a phase for further purification that uses guided filtering technique which improved the overall performance and preserved the accuracy of the information [27]. Salamahn *et al.* proposed and designed an algorithm to remove thin cloud effect for remote sensing imagery. The proposed method is considering the use of infrared satellite imagery the system is based on the analysis of infrared satellite images which ultimately may fail in detecting and removing areas contaminated by thin cloud or general cloud shadow knowing that these effects do distort the real signal received by satellite sensor, hence hindering the final removal performance [21]. 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. Thin clouds disappeared visually. With a nearly cloud-free image acquired on 14 April 2014 as the “truth”, the spatial coefficient between the “truth” image and the image before and after the algorithm increased from 0.47 to 0.83 for band1, 0.55 to 0.82 for band2, 0.73 to 0.88 for band3, and 0.82 to 0.88 for

band4. The increase of the spatial coefficients quantitatively indicated the validity of the algorithm [25].

However, in general circumstances, the atmospheric properties are not straightforward to be acquired and analyzed. This also applied when even if a pre-plan for this purpose. Essentially it is proofed that the model-based methods fail in evocatively competing the effect of locally dense thin cloud. Therefore, the effort of proposing and designing a new image-based method for thin cloud removal in remote sensing images is a necessity in order to independently obtain the needed thin cloud elimination and correct the impact of cloudy pixels on the ground object. In this regard, homomorphic filtering is widely used for correcting non-uniform illumination in images. The illumination-reflectance model of image formation concludes that the intensity at any pixel, which is the amount of light reflected by a point on the object, is the product of the illumination of the scene and the reflectance of the objects in the scene; the image-based strategies are divided into the following classifications:

1. The multi-image based strategy enhances the illumination of the cloudy pixels by intertwining correlative information from various worldly or another detecting component. There are some points of confinement to the multi-image based over different phases. Firstly, the cloudy image should be essentially related to the reference without cloud images; if not, the combination can bring about breaks or mistakes inside the effects. Secondly, the cloud inside the numerous photos shouldn't cover a comparable area; generally, no corresponding information needs to reestablish the ground information. Thirdly, geometric and radiometric adjustments are fundamental preprocessing, and along these lines the institutionalization exactness straightforwardly related to the last combination result. Multi-image based thin cloud elimination procedure has serious requirements for information that restrain their application.
2. The single-image strategy is primarily based on area unit of the documented knowledge; so, their applications are restricted to only unit area.

Thin cloud removal needs to be reinvestigated and significant improvements should be provided. Generally, thin clouds removal by bar chart matching has been the most widely used methodology [21,23]. A typical image-based region correction methodology aims at the dark object deduction which treats all pixels equally [1]. However, clouds are liquid droplets and totally different particles deferred among the atmosphere and area

unit approachable distributed rather than globally. Any thin cloud removal proposed procedure should be capable of eliminating the influence of the universal path radiation at the same it should not fail in inducing obviate native thin clouds. A grade based methodology for thin cloud removal should be established to filtering the thin cloud into several levels through thin-optimized makeover before the correction intended for the detection and characterization of cloud allocation at terrestrial sat scenes which will be the aimed objectives of this research.

1.3. Research Objectives

The main objective of this research is developing a robust and feasible model for thin cloud removal based on homomorphism filtering. However, this objective is sub-divided to the following objectives:

1. To investigate the literature review related to thin cloud removal based on various methods and proves the feasibility of homomorphic filtering as the best candidate for brightening component reduction as well as the expansion of reflection coefficients using the improved homomorphism.
2. To develop the improved homomorphic filtering model mathematically as well as its MATLAB implementation for experimental analysis and result evaluation.
3. To benchmark the obtained results with the most relevant model found in the literature in order to prove the feasibility of the developed model.
4. To highlight any possible directions for the research based on the current study as baseline for future research.

1.4. Research Methodology

The methodology of this research is based on developing an homomorphic filtering that incorporates an improved homomorphism phase method which operates based on semi-automatic tuning for the optimal cut-off frequency in order to obtain the best reduction on thin cloud effects. In order to preserve pixels' clarity and ensure the high fidelity of the results, cloudy pixels are detected and handled separately. To circle the unique pixels and make certain the high devotion of the outcome, cloudy pixels are identified and taken care of independently. As low-frequency information, cloud free water

surfaces are being especially gathered and adjusted. As a validation step, the resulted purified images are benchmarked with the same images results obtained from related models found in the literature. The final remarks are then provided based on the obtained results benchmarking to form an open research area for future investigation.

1.5. Thesis Organization

This thesis is systematic as follows:

- **Chapter I:** General introductory section which presented the needed overview about thin cloud removal as well as a thorough review of the literature. It also provided the objectives of the research and methodology which is followed in conducting the experimental work.

- **Chapter II:** Investigates the models used for thin cloud removal with a main focus on homomorphism. It also provides the details of image processing tools and methods which are used in course of this research.

- **Chapter III:** This chapter presents and discusses experimental results obtained from homomorphic filtering applied in our study. The chapter also provides a benchmark for the performance by comparing the obtained results with most relevant models found in the literature.

- **Chapter IV:** This chapter provides a guideline for most recent competitive method found in the literature by implementing the method and discussing its pros and cons and providing directions for further research based on it.

- **Chapter V:** This is the final chapter which it is dedicated to concluding final remarks on the work of this thesis as well as providing the final insight on possible ways for further enhancing the work in future studies.

1.6. Summary

This chapter presented an introductory session for the thesis in which a general idea about thin cloud removal has been presented as well as related research work and attempts. The chapter also included the research problem, objectives, methodology, and final organization of the thesis.

2. BACKGROUND

2.1. Introduction

In this chapter, the discussion is guided towards understanding thin cloud structure and how they can be considered in various models. Also, the discussion is covering the most relevant methods for thin cloud removal and the models or tools used for that. Within the general discussion, image processing methods and techniques used for thin cloud removal are provided and investigated.

2.2. Overview

Clouds are defined as aerosol visible floating objects containing water droplets as well as fine ice particles distributed based on their category or type over different latitudes [26, 27]. They are created inside the earth's thermosphere once the water evaporates from oceans, lakes, ponds, running streams and rivers. The vapor rises up into colder area of the atmosphere as a result of convective, orographic, or front lifting which referred to as adiabatic cooling. The vapor may contain various particles from mud to minute element of salt and garbage. The vapor in high levels gets condensed and the clouds become obvious. Clouds may vary latitude, color, physical structure, and other characteristics [27]. Clouds physical structure as well as properties and characteristics are very important for this research study. For this reason, in the following subsections, clouds classification as well as their properties is presented.

2.3. Cloud Types

Clouds are generally distributed from the bottom mesosphere, stratospheric, and tropospheric categories are listed based on their height. At intervals the troposphere stages of non-vertical clouds listed in falling order of height. The genus varieties at intervals every stage organized in falling order of average base height. The constituent species, variations, supplementary option and standard clouds organize in approximate order of frequency of incidence. Vertical or multi-stage cloud teams and their constituent categories

and species listed in ascending order of average height of cloud first-rate. Their variation, supplementary option, and standard cloud organize so as of approximate frequency of incidence. A count of basic tropospheric variation that shown as variety in parentheses once every selection, once cumulonimbus cloud that has no subtype, and once bound species aren't invariably dividable into verities. Different planets in a very solar system that have clouds listed so as of their distance from the sun and therefore the clouds every planet are in approximate falling order of height. Specifically, clouds can be categorized based on their physical structure, properties as well as latitude to the following 10 types [28]:

1. High clouds:

- **Cirrus:** These clouds are among the highest in the atmosphere. They generally appearing detached white filaments patterns with narrow distributions. This type of clouds is considered transparent but transparency degree depends on their content of ice crystal, the separation of these crystals, chemical contents and filaments distribution. The typical appearance of these clouds is shown in Figure 2.1.
- **Cirrostratus:** This type of clouds appears as a smooth strand of whitish veil. The main difference between this type and cirrus is that this type is usually extensive and spans to cover wide areas compared to cirrus as shown in Figure 2.2.
- **Cirrocumulus:** This type is represented by a layered white patch of clouds that do not create shading. The general appearance of this type does not look like a white strand rather it looks like irregular ripples or grains in the sky. Experts state that there is a common relationship between cirrus and cirrocumulus which basically reflects on their characteristics. This type is illustrated in Figure 2.3.



Figure 2.1. Cirrus clouds[28]



Figure 2.2. Cirrostratus clouds[28]



Figure 2.3. Cirrocumulus with cloudy area[28]

2. Mid clouds

▪ **Altostratus:** This type of clouds are represented by fully or partially connected gray or bluish-like sheets which cover wide aerosol areas. The clouds of this type are not thick; rather they are considered relatively thin and pass the sunlight through them as if they are some sort of light sunglasses. An example of this cloud type is given in Figure 2.4.

▪ **Altostratus:** What distinguishes altostratus clouds is mixed patch pattern where white and gray strands are diffused together to form this layered cloud type. This type is relatively dark in color and creates a corona when it passes in front of the sun. Also, it is often to find that this type is created from many layers to create concrete cloud structure as seen in Figure 2.5.

▪ **Nimbostratus:** These types of clouds are generally considered as rainy clouds. The clouds in nimbostratus are created as consequence of massive concatenation and thickening of altostratus. The appearance of this type is usually gray or dark gray which produces rain or snow. This type is known to be very thick and can fully or partially block sunlight. A typical example of this type is shown in Figure 2.6.

3. Low clouds

▪ **Cumulus:** This is type of clouds are generally detached and dense clouds. The most special characteristic they have is that their edges are sharp and they are much lighter and whiter than their middle part. These types of clouds partially block sunlight which passes through the detachments within the clouds. A typical example of cumulus is shown in Figure 2.7.

▪ **Stratus:** This type has a dark gray color and relatively uniform structure. The clouds of this type may produce snow grains or ice prisms on a condition that they have enough thickness for that. This type is shown in Figure 2.8.

Cumulonimbus: The clouds of cumulonimbus present in a dense mountain-like of relatively dark layer. The structure may appear in the form flat concrete shape. This type may seem as smooth layers that merge together to create a tower-like cloud. Generally, these clouds produce thunderstorms. A typical example is illustrated in Figure 2.9.



Figure 2.4. Altostratus clouds[28]

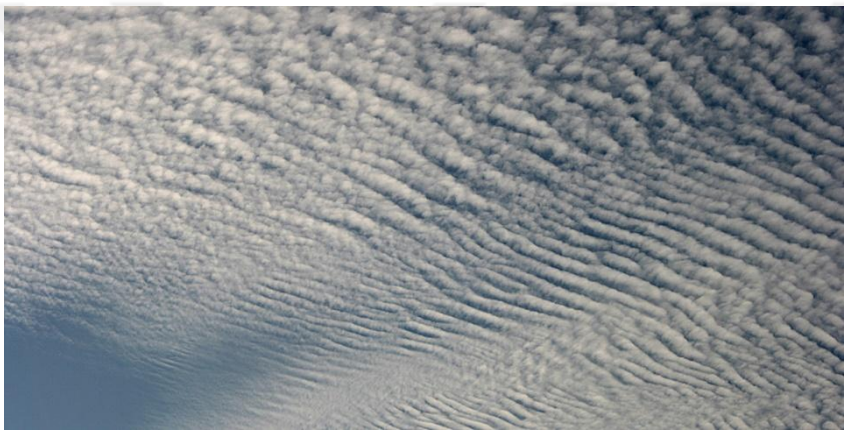


Figure 2.5. Altocumulus clouds[28]



Figure 2.6. Nimbostratus area clouds[28]



Figure 2.7. Cumulus clouds[28]



Figure 2.8. Stratus clouds[28]



Figure 2.9. Cumulonimbus clouds[28]

▪ **Stratocumulus:** This type is generally gray or semi-white patched-like or layered clouds. They appear in what looks like honeycomb which is darker from bottom. The general characteristic of this type of clouds is that they do not merge and they do not have strands and they are usually smaller than other types in the patches area. The typical example of this type is shown in Figure 2.10.



Figure 2.10. Stratocumulus clouds[28]

The most relevant to this study is basically cirrus and cirrocumulus which are considered as thin clouds that match with the research criteria.

2.4. Thin Clouds

As explained above, the concern and focus will be guided toward what is considered as “thin cloud”. The term thin cloud here needs to be properly defined and explained in order to clarify the precise idea. Clouds can be characterized by the filtering level of transmission, reflection and absorption properties that they show to solar radiations (basically the sunlight) [26]. In addition, clouds geometry (area and thickness) much affects the transparency of the clouds. According to the brief investigation of cloud types in previous subsection and to some references [29-31], the consideration of thin cloud may fall within cirrus, stratus and small cumulus. Therefore, the consideration of this research is limited to the characteristics that match with the basically any cloud cover similar to those. In essence, thin clouds do not obscure the whole ground information in satellite imagery,

rather they create a blur and confusion in ground features which can be extremely sensitive and need to displayed in high resolution format.

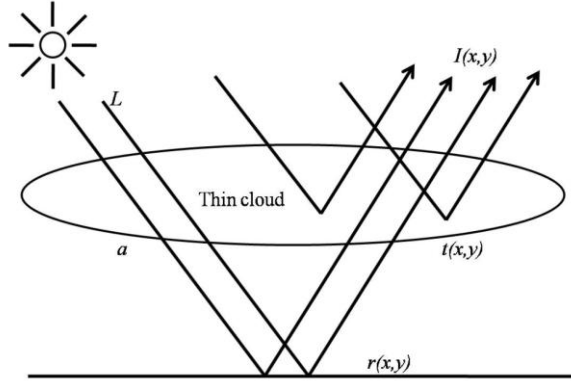


Figure 2.11. Commonly Used Physical Model of Thin Cloud[32]

2.5. Thin Cloud Modelling

The commonly accepted physical model for thin cloud is illustrated in Figure 2.11[32]. Basically, due to the attenuation, scattering, and reflection resulted from the thin cloud, the recorded image will be distorted and can be represented as in Equation 2.1 below [32]:

$$l(x, y) = \alpha L r(x, y) t(x, y) + L(1 - t(x, y)) \quad (2.1)$$

Where $I(x,y)$ is the intensity of the detected image by the satellite, 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 Equation 2.1, $L(1 - t(x, y))$, should be removed.

2.6. Summary

In this chapter a general discussion related to cloud types, characteristics and physical properties. This discussion aimed at introducing the proper definition and categorizing what meant by thin cloud in our study. In addition, the chapter has presented a generic model for thin cloud and their effect on satellite imagery which will be used in further chapters for modeling and analysis.



3. METHODOLOGY

3.1. Introduction

This chapter presents the methodology followed by in this research. It also discusses the idea of homomorphic filtering as it's the main concept used for thin cloud removal in this research. Some applications are also presented and discussed as they are needed for methodology clarification and presentation.

3.2. Methodology Steps/Flowchart

In this chapter, a straightforward thin cloud removal method is presented by using HF. The block diagram of the HF can be seen in Figure 3.1. The thin cloud confirmed the images, such as HF from the thin cloud image is very difficult to analyze due to its gray scale and very small changes in intensity between the pixels of the images. There are various techniques used to reduce thin cloud in the image. HF determines the high-pass filter value of a group of values that has been sorted in an ascending order. The high-pass frequency always comprises of a low-pass frequency of values and the size of the high-pass frequency frames is also odd. The size of the high-pass frequency frame which also called the thin has a fixed size it can be 3 x 3, 5 x 5, 7 x 7, and so on.



Figure 3.1. The block diagram of HF [33]

In the implementation of HF, 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. HF algorithm is described in following steps:

Algorithm 3.1**Input:** Thin cloud image.**Output:** Filtered image.**Step1:** Read the original image.**Step2:** Log- transformed image with zero-padding in blocks of $w \times w$ window.**Step2.1:** Use FFT and apply the values of high-pass pixel in ascending order.**Step2.2:** Compute the inverse FFT.**Step2.3:** Crop the image back to the original unpadded size.**Step3:** Repeat step 2 until the process is completed for the entire image.**Step4:** Apply the exponential function.

A high-pass filter can be used to make an image sharper. A high-pass filter works in exactly the same way as low-pass filter, which simply uses a different convolution nature frequency. Thus, an improved high-pass filtering can be obtained. At improved filtering the apply high-pass filtering to log-changed images, the high-pass filtering steps give us a chance to at the same time apply different upgrade images. Consider an altered adaptation of the high-pass filter $H(u,v)$ that we utilized last time. Using of HF brings about bringing down the images differentiate. Along these lines, an improved HF, $H_i(u, v)$ which is called Improved HF, is utilized by including value esteem and a scaling component as take after:

$$H_i(u, v) = \alpha + \beta H(u, v), \quad \alpha < 1, \beta > 1 \quad (3.1)$$

If $\alpha < 1$ and $\beta > 1$, this will amplify the high-frequency modules more than the low-frequency module.

The IHF improves the traditional HF method. The flowchart of the IHF is given in Figure 3.2. As it can be seen in the related figure, the IHF method consists of various components such as color channel decomposition, applying IHF to each color channel and combining filtered color channels to obtain the output image. After color channel decomposition, the IHF is constructed by improving the high-pass filter. To this end, two parameters namely alpha and beta are employed to strength the filtering ability of the high-pass filter. Finally, filtered each color components are combined to obtain the filtered output image. The motivation of such improvement aims to amplify the high-frequency

components more than the low-frequency components. IHF algorithm is described in following steps:

Algorithm 3.2

Input: Thin cloud image.

Output: Filtered image.

Step1: Read the original image.

Step2: Log- transformed image with zero-padding in blocks of $w \times w$ window.

Step2.1: Use FFT and determine alpha and beta parameters.

Step 2.2: Obtain the emphasized high-pass filtering structure and apply the values of high-pass pixel in ascending order.

Step2.3: Compute the inverse FFT.

Step2.4: Crop the image back to the original unpadded size.

Step3: Repeat step 2 until the process is completed for the entire image.

Step4: Apply the exponential function.

3.3. High-pass Filtering Cut-off Frequency

A high-pass filter is an electronic filter that passes signal with a frequency higher than a certain cut-off frequency and the attenuation for each frequency depends on the filter design. A high-pass filter is usually modeled as a liner time-invariant system. It is sometimes called a low-pass filter or bass-cut filter. High-pass filters have many uses, such as blocking DC from circuitry sensitive to non-zero average voltages or radio frequency devices. They can also be used in conjunction with a low-pass filter to produce a band pass filter, as shown in Figure 3.3. Equation 3.6 can be used for determining the cut-off frequency as the change will take place in R and C values.

In remote sensing imagery, the high-pass filter substance is still not entirely clear. Thin cloud filter substance consists of high-pass frequency, the thin cloud removal that project including the high-pass frequency and the cleaning from the point of cut-off frequency. One feature of thin cloud removal is conducted by choosing the high pass frequency in image processing to find the point that has a high-pass frequency and clean that area to find new clear area by using a HF to remove thin cloud effects.

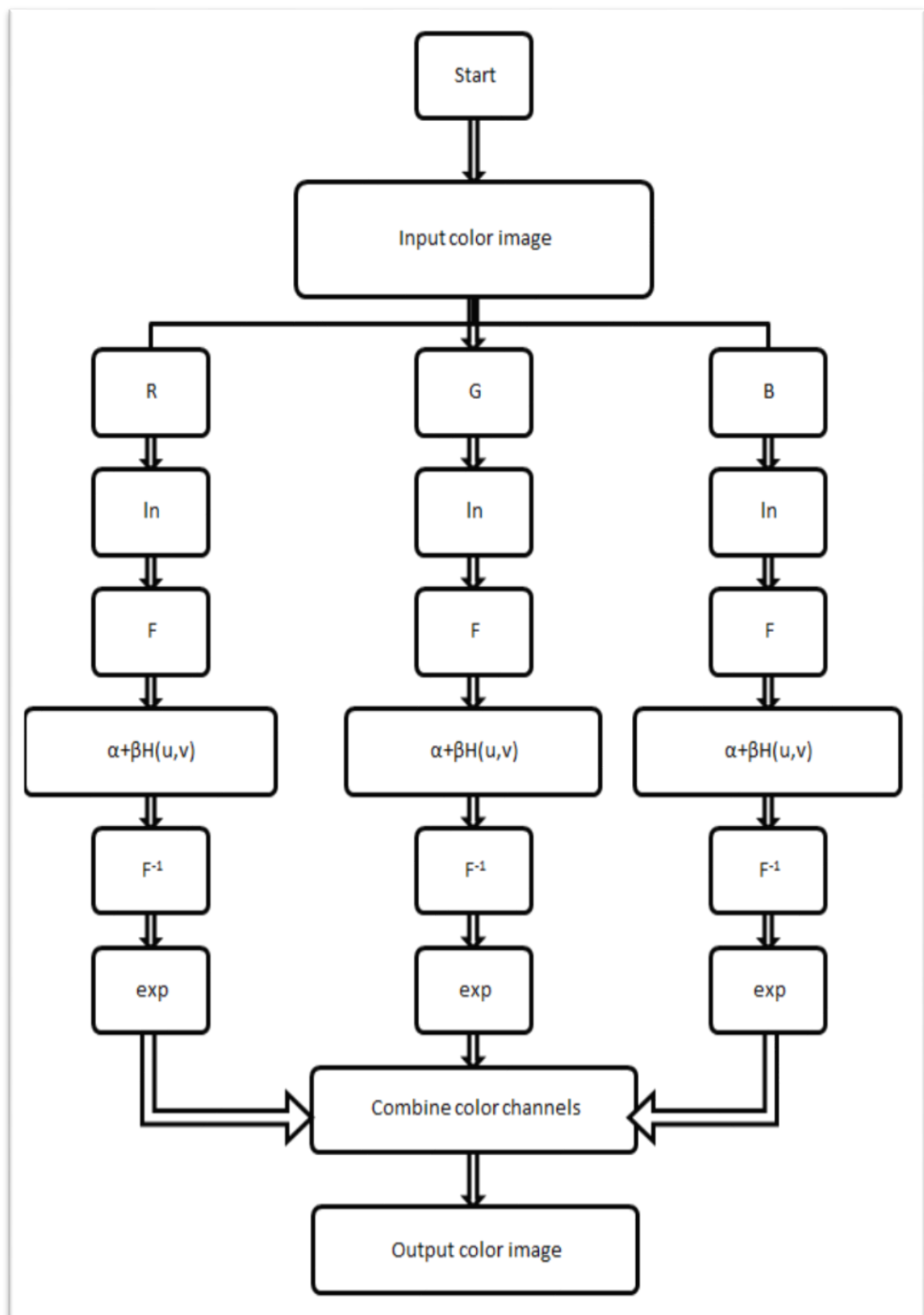


Figure 3.2. Block diagram of the proposed methodology

The confidential process by this regions are classified according to the global distribution of pixels in a gray-level and spatial relationship between the unsure gathering. The Homomorphic filtering to create the thin cloud removal images are applied. This algorithm determines by assigning membership to each point of data corresponding to the center of each high-pass filter on the basis of distance among data point and thin cloud center.

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. 3.3. In Fig. 3.3, 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.

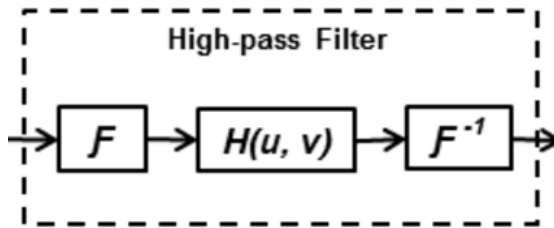


Figure 3.3. The block diagram of high-pass filter [33]

To still be able to use the usual high-pass filter, the logarithm's operation is needed to convert the multiplication to addition. Particular, the steps of this algorithm are [25]:

- Calculate logarithm of input light signal:

$$L'(x, y) \triangleq \log L(x, y) = \log[R(x, y)I(x, y)] \quad (3.1)$$

$$= \log R(x, y) + \log I(x, y) \triangleq R'(x, y) + I'(x, y) \quad (3.2)$$

- Apply 2D Fourier transform of the signal $L'(x,y)=R'(x,y)+ I'(x,y)$

$$L(u, v) \triangleq F(L'(x, y)) = F(R'(x, y)) + F(I'(x, y)) \triangleq R(u, v) + I(u, v) \quad (3.3)$$

Where $R(u,v)$, $I(u,v)$ and $L(u,v)$ are the spectra of the corresponding spatial signals $R'(x,y)$, $I(x,y)$ and $L'(x,y)$, respectively.

- Obtain the low frequency components in domain

$$H(u, v)L(u, v) = H(u, v)R(u, v) + H(u, v)I(u, v) \quad (3.4)$$

Where $H(u,v)$ is a filter in the frequency domain whose entries corresponding to the low frequencies are smaller than 1 while the rest entries are 1 to keep the high-frequency components in the signal unchanged.

- Calculate reverse the convert

$$L'(x, y) \triangleq F^{-1}[H(u, v)L(u, v)] = F^{-1}[H(u, v)R(u, v)] + F^{-1}[H(u, v)I(u, v)] \quad (3.5)$$

$$\triangleq R(x, y) + I(x, y) \quad (3.6)$$

- Take exponential operation

$$\begin{aligned} L(x, y) \triangleq \exp[L'(x, y)] &= \exp[R'(x, y) + I(x, y)] \\ &= \exp[R'(x, y)] \exp[I'(x, y)] \triangleq R(x, y)I(x, y) \end{aligned} \quad (3.7)$$

• In accordance for this procedure is called HF process, $I(x,y)$, the processed illumination should be considerably reduced due to the high pass filtering effect, while the reflectance $R(x,y)$ after this procedure should still be very close to the original reflectance. That is, color constancy results as the color of the surface is not affected much by the color illumination [27].

3.4. Low-pass Filtering Cut-off Frequency

A low-pass filtering is a filter that passes signals with a frequency lower than a certain cutoff frequency and attenuates signal with frequencies higher than the cutoff frequency. The exact frequency response of the filter depends on the filter design. The filter is sometimes called a high-cut filter, or treble cut filter in audio applications. A low-pass filter is the complement of a high-pass filter.

In this research experiment, the homomorphic filtering method is applied to the thin cloud of the image using homomorphic filtering. The maximum number of sigma in this experiment is set to 2.5 where the number of parameter affects the image output quality; however, the execution time is increased. Different values of low-pass frequency and high-pass frequency are used, and the amount of thin cloud imposed on the integrals inside and

outside the image is different. In addition, the equality of cutoff frequency demonstrates fair competition inside and outside the boundary during using homomorphic filtering.

More accurate representation of low-pass cut-off frequency is shown in Figure 3.4.

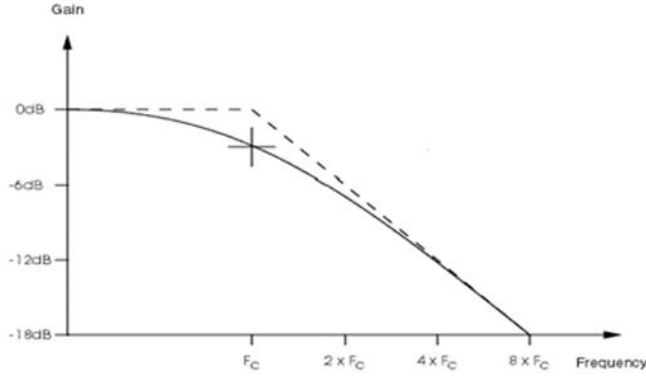


Figure 3.4. Low-pass filter diagram

In order to maintain an improved determination of the cut-off frequency, γ (scale parameter is used in this experimental) is set to 1.5. Increasing scale parameter values correspond to dependency of the location of the initial outline while decreasing values corresponds to a more exact location of the object boundaries.

The filter recurrence relation provides a way to determine the output samples in terms of the input samples and the preceding output. The following sample code algorithm simulates the effect of a low-pass filter on a series of sample algorithmic implementation [13]:

3.5. Summary

This chapter described the research methodology for thin cloud removal based on HF and IHF algorithms. The chapter discussed the process of research and operational structure for achieving objectives of this study. Moreover, algorithms 3.1 and 3.2, proposed methods are presented in detail.

4. RESULTS AND DISCUSSION

4.1. Introduction

This chapter presents the description of the results obtained from the implementation of the proposed methods that could provide us with useful information and regarding the efficiency of the proposed method; aiming to properly benchmark the ultimate performance of the proposed method.

4.2. Data Collection and Procedure Description

In this research's experiment, a standard dataset of thin cloud was collected for cloud removal using HF and IHF. A total of 13 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 was used for evaluating the proposed methods and the output of each stage is presented and discussed. Subsection 4.2.1 to 4.2.2 deals with the removal of thin cloud by using HF and IHF on satellite images and how to create image gathering. All experiments implementation is done in MATLAB environment with a Windows operating system machine of (64-bits) and 2.53GHz processor.

4.2.1. Initial Steps of Thin cloud removal

In this research, HF and IHF were used to remove thin cloud in several sub-steps. First, the initial HF and IHF parameters were tuned and the Gaussian high pass filtering is adopted in all experiments. In addition, the parameters of the Gaussian high pass filtering needs to be tuned. Thus, all parameters were arranged optimally during the experimental works. An illustration filtering result was given in Figure 4.1., where Figure 4.1. (a) Shows the original image and Figures 4.1.(b, c) shows the HF and IHF filtered results, respectively. By visual inspection, the IHF yielded a little bit enhanced output image comparable to HF method.

4.2.2 Results by HF

In this sub-section, the results by HF method were given and discussed. Our experiments were conducted in order to evaluate the effect of the parameters of HF on thin cloud removal. To do that, we used various HF parameters and conducted the experiments. The obtained output images were recorded in Figure 4.1.

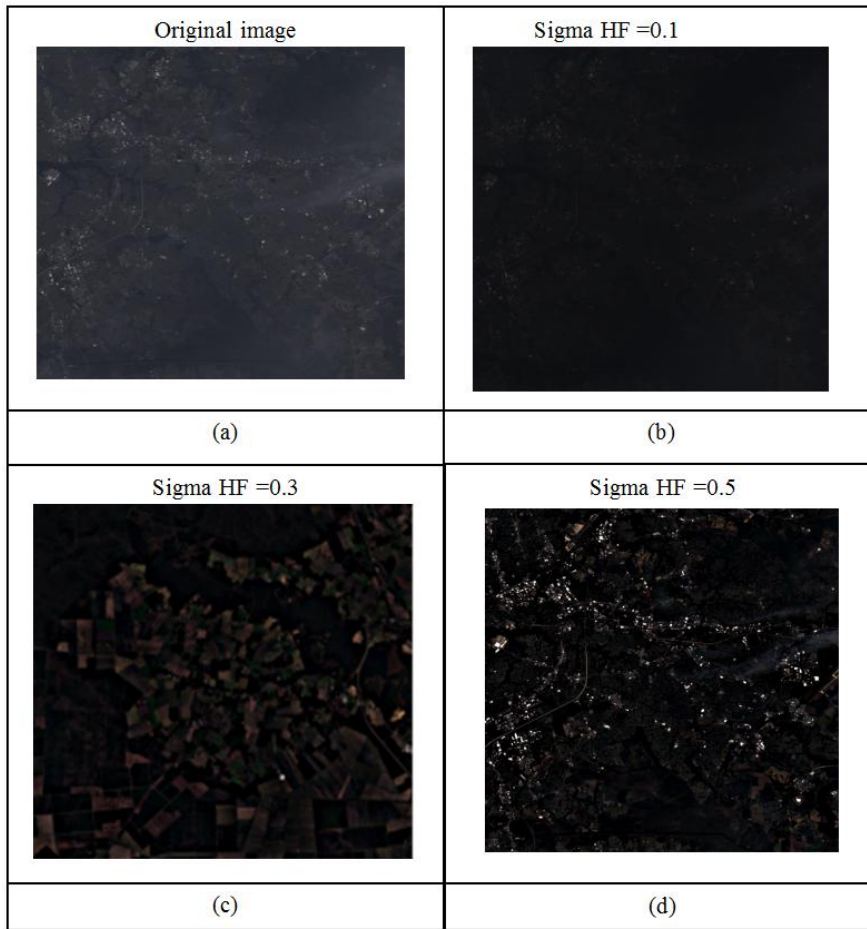


Figure 4.1. Thin cloud removal using HF: (a) original image, (b) sigma = 0.1 (c) sigma =0.3 and (d) sigma = 0.5.

As it can be seen through the output image series, an increase in sigma yielded an enhancement in the contrast of the output image. In addition, the thin cloud was not visible after HF. While sigma = 0.1, a darker output image was obtained and while sigma = 0.5, a lighter output image was constructed. These results indicate that sigma parameter is quite efficient in order to obtain an enhanced output image.

4.2.3 Results by IHF

In this sub-section, the results by IHF method were given and related discussed. Our experiments were conducted in order to evaluate the effect of the parameters of IHF on thin cloud removal. To do that, we used various IHF parameters and conducted the experiments. The obtained output images were recorded in Figure 4.2.

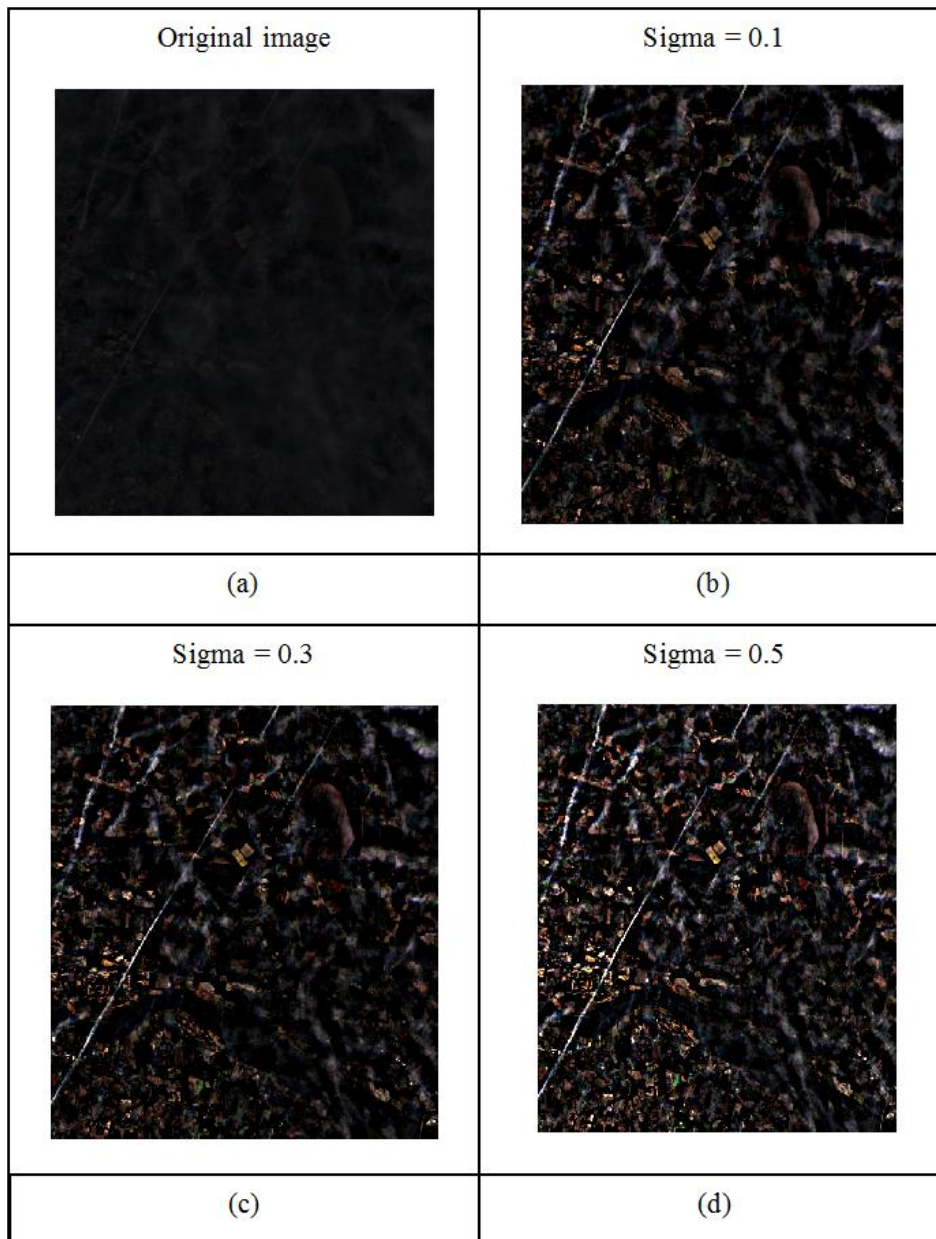


Figure 4.2. Thin cloud removal by IHF algorithm: (a) the original image, (b) sigma = 0.1, (c) sigma = 0.3, (d) sigma = 0.5.

It is obvious that IHF produced better results. In other words, more enhanced output images were recorded in Figure 4.2. Similar to the HF results, an improved contrast is visible through the output image series, when an increase is visible in sigma. In addition, the thin cloud was removed with IHF. The alpha and beta values were set 0.5 and 1.5, respectively.

We constructed more experiments to validate the efficiency of the IHF. Thus, some new results are given in Figure 4.3. Figure 4.3. shows the evolution of IHF for thin cloud removal. The alpha and beta parameters were fixed to 0.5 and 1.5 and the various sigma values were considered. The tuned sigma values are show over the related figure in Figure. 4.3.

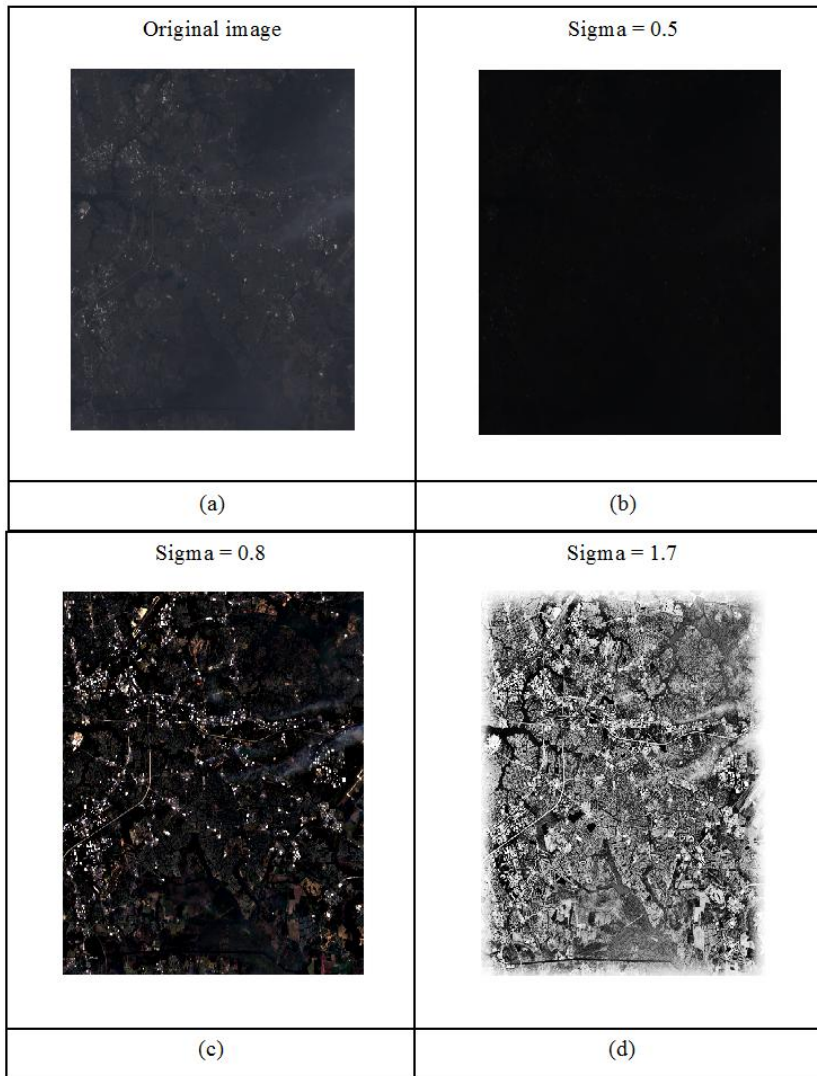


Figure 4.3. IHF for thin cloud removal: (a) original image, (b) sigma = 0.5 , (c) sigma = 0.8, (d) (A gray scale image) sigma = 1.7

In Figure 4.3., new results were given with different sigma values. In addition, a gray scale image was also used to determine the efficiency of IHF method. The result shows that the IHF can also remove thin cloud on gray scale images.

4.2.4. Weak IHF

This subsection discusses the borders of the applicable values for a and β where the filtering process is still acceptable. The values of a and β affect the purification process either positively or negatively. The experimental procedure is conducted a number of times in order to obtain the possible range of both parameters and their effect on the outcomes. Increasing the values of both parameters above 1.5 creates an excessive brightness effect on the image which ends up generating a weakly filtered. However, decreasing the values of both parameters below 0.5 creates another sort of weak filtering as depicted in Figure 4.7. and Figure 4.8. Therefore, for optimal results, it is recommended keeping the values of a and β within the range of 0.5 and 1.5.

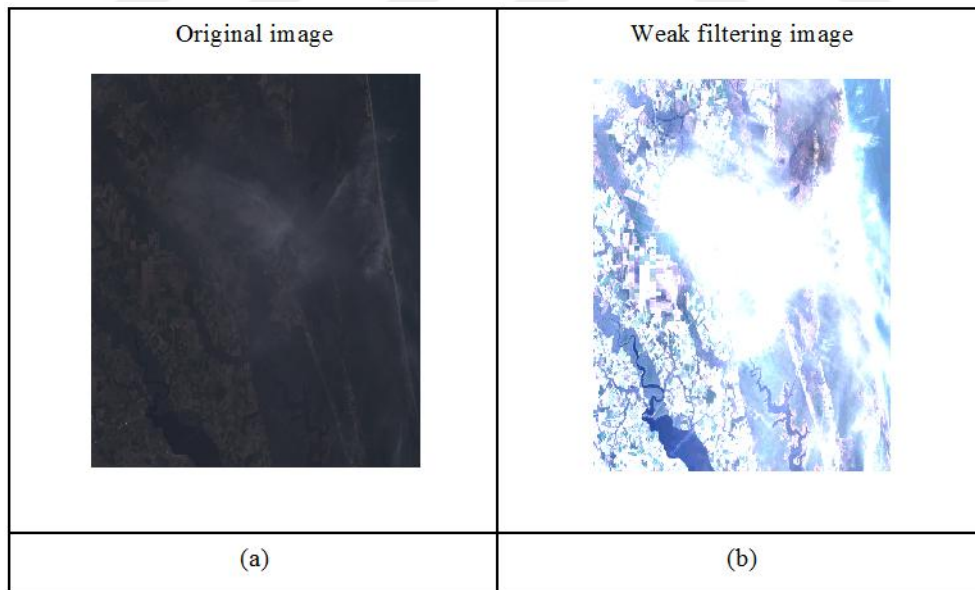


Figure 4.4. Failure section: (a) original image, (b) weak filtered image due to high darkness impact.

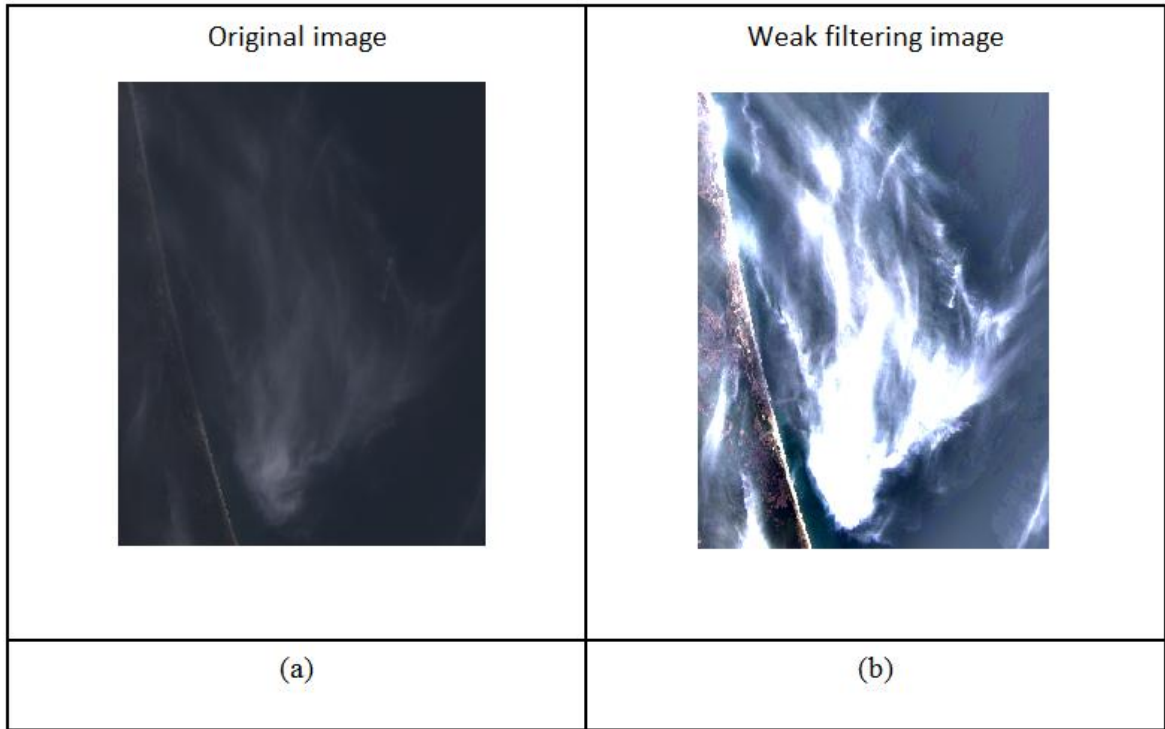


Figure 4.5. Failure in filtering: (a) original image. (b) Weak filtered image due to cloudy effect.

4.2.5. Comparison of HF and IHF

In this subsection, we carried out a comparative work where HF and IHF methods were used in thin cloud removal. The obtained results were evaluated visually. In this comparison, 5 image patches were used that were covered by thin clouds. The obtained results were shown in Figure 4.9. The first, second, and third columns of Figure 4.9 show input images; HF filtered images and improved HF filtered images, respectively. In the last column of the figure, we specified the related parameters. In all experiments, we used a Gaussian high-pass filter. The sigma value of the Gaussian high-pass filter is tuned during experiments. In addition, the alpha 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 Figure 4.9, 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 than the HF method. But it should be mentioned that there are some cloudy parts in the filtered image. Two better results can also be seen in the second and fourth rows of Figure 4.9. These input images looked like that they contain a uniform haze. As shown in the second column of table 4.1, the HF did not produce 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. The third row in Figure 4.9, 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 Figure 4.9, 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.

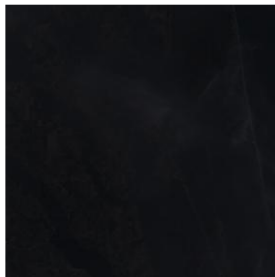
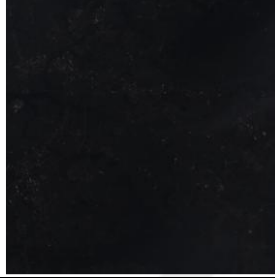
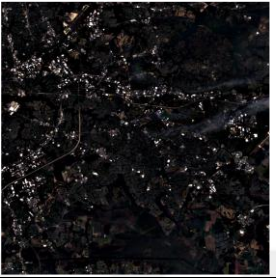
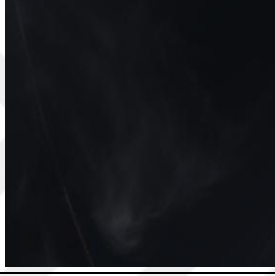
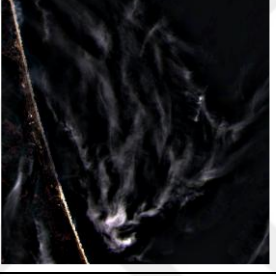
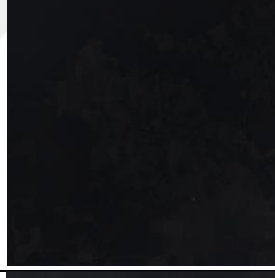
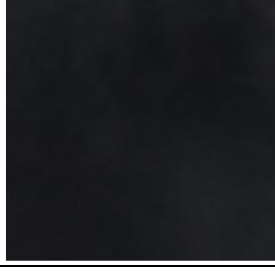
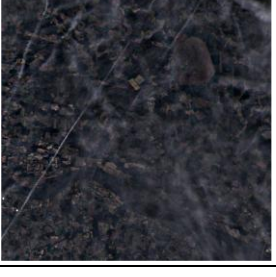
Original image	Homomorphic filtering	Improved HF	parameters
			HF sig: 0.1 Emp. HF sig: 10 Alpha: 0.5 Beta:10
			HF sig: 0.2 Emp. HF sig: 10 Alpha: 0.5 Beta:15
			HF sig: 0.3 Emp. HF sig: 10 Alpha: 0.5 Beta:20
			HF sig: 0.4 Emp. HF sig: 10 Alpha: 1 Beta:20
			HF sig: 0.5 Emp. HF sig: 15 Alpha: 1.5 Beta:20

Figure 4.6. Compare of the result between HF and IHF

4.3. Summary

Based on the idea of getting the best output images before performing HF with the thin cloud images, this study has extended the HF and the improved HF method to reduce

thin cloud sensitivity, thin cloud problems and darkness intensity. From the comments and analysis, we can see that the proposed method is reasonable and reliable in simple, intermediate and complex cases. Experiments have also shown that the proposed method is better than the last existing method.



5. CONCLUSION

5.1. General Conclusions

This study was proposed in an effort for enhancing the quality of remote sensing satellite imagery. The aim was guided to thin cloud removal that contaminates satellite images and weakens 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 homomorphic filtering; improved homomorphic filtering of thin cloud removing that has been passed through high-pass filtering stage. The cut-off frequencies were determined in semi-automatic way which improved the total performance of the algorithm. During the implementation of the methodology, three main algorithms were developed and presented which can be applied for any satellite imagery in order to purify them from the effects of thin cloud. Basically, these algorithms were developed based on mathematical modeling and analysis of thin cloud as well as homomorphic and improved filtering. The results were encouraging and a bunch of images were used to determine the performance of the developed method where only two were recoded as failed filtered.

Experimental results indicate that the proposed method is superior and has a future application for thin cloud removal. Furthermore, the developed method in terms of modeling as well as the mathematical and programming implementation is considered not complex. This means processing time, energy and effort will be lessened compared to other methods found in the literature.

Generally the technique is limited to remove thin cloud and can bring about without cloud images with high fidelity cloud. The techniques are basically divided into three main stages: High-pass filtering phase, homomorphic and improved filtering phase method.

IHF is generally a useful tool in enhancing image accuracy level especially considering high frequency noise components. However, it may not be applicable as a generic enhancement technique, but it works well on a certain filtered of problems, as in the case of this research.

5.2. Further Work

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. In addition, satellite imagery contaminated by thin cloud has a complex point to remove as well as some undistinguished components. It can be useful to further analyze these undistinguished contents to be categorized and precisely locate aiming at further enhancement of the overall clarity. Finally, the applicability of the developed algorithm can be investigated and adjusted to be used in some applications like locating kidney stones, cysts, breast cancer, and tumor in brain, etc.

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