Applying Image Enhancement Techniques for Improving the Quality of Historic Amharic Manuscripts

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ACCEPTANCE

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Accepted by the Faculty of Informatics, St. Mary's University, in partial fulfillment of the requirements for the degree of Master of Science in Computer Science

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DECLARATION

I, the undersigned, declare that this thesis work is my original work, has not been presented for a degree in this or any other universities, and all sources of materials used for the thesis work have been duly acknowledged.

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LIST OF ACRONYMS AND ABBREVIATIONS

DIP:	Digital Image Processing
DPI:	Dot per inch
ENALA:	Ethiopian National Achieve and Library Agency
MAE:	Mean Absolute Error
MATLAB:	MATrix LABoratory
MSE:	Mean Square Error
OCR:	Optical Character Recognition
PSNR:	Peak signal to noise ratio

ABSTRACT

A large number of manuscripts are found in various institutions, archives and other museums and it is common for archive libraries to provide public access to historical and ancient manuscript digital image collections to protect original hard copies from damage and also to improve access. The Ethiopian National Archives and Library Agency (ENALA) is in the process of digitizing its historical manuscript collections and there is a need to ensure the quality of the digital images of the manuscripts. This study is initiated with the objective of testing various image noise filtering algorithms for their effect on enhancing digital images of manuscripts under different conditions. Six historical manuscripts from the early years of the 20th Century and two from each of manuscripts in good, medium and poor conditions were purposely selected for this study. Images of each manuscript were taken using digital cameras with 8 and 16 megapixel resolution. The images were filtered using mean, median, Gaussian, morphological dilation and morphological erosion algorithms with convolution kernel size of 3 by 3 and 5 by 5. The PSNR, MSE and MAE are used as parameters of evaluation of the effectiveness of the various filtering algorithms. The result has shown that similar trend of the three parameters for all images and filtering algorithms. In addition correlation values of higher than 0.87 were found for the parameters between themselves. For the first set of image PSNR values of 21.64, 19.14, 16.78, 12.89 and 12.60 are obtained for the median, mean, Gaussian, morphological dilation and Morphological erosion algorithms. Similar trend was observed for most of the other images. No consistent effect of image resolution was observed but images of 8 megapixel have shown better quality after filtering images of manuscripts in good and poor conditions, whereas images from manuscripts of medium condition with 16 megapixel has produced better images upon filtering. Kernel size at 3 by 3 was found to be better than 5 by 5 for enhancing image quality. From the experimented filtering algorithms, median filtering algorithm with 3 by 3 kernel size is proved effective to improve the quality of images of historical manuscripts. Digital images taken at a minimum resolution of 8 megapixels appear to be adequate for images of historical manuscripts. Evaluation of advanced image filtering techniques is recommended for improving the quality of highly degraded manuscript images.

Keywords:

Image enhancement, filtering algorithms, resolution, kernel size, historical manuscripts

CHAPTER ONE

INTRODUCTION

1.1 Background

A large number of manuscripts are found in various institutions, archives and other museums. Such documents are of significant importance as source of information and input for research, academic and other purposes. It is common for archive libraries to provide public access to historical and ancient manuscript digital image collections [1], instead of original analogue forms. This creates a need for transcribing the manuscripts into a textual electronic format for digital libraries.

Accordingly, national archives have started digitizing historical manuscripts [2]. The digitization of the manuscripts can be effected through scanning with scanners or photographing with high resolution cameras of which the latter is appropriate for highly fragile manuscripts [3] [4]. While it is preferable to acquire image data at a higher resolution to begin with, one can imagine a wide range of scenarios where it is technically not feasible. In some cases, it is the limitation of the sensor due to low-power requirements as in satellite imaging, remote sensing, and surveillance imaging. In other cases, it is the limitation of the sensed environment itself; for example, the presence of atmospheric clutter, background noise and unfavorable weather [5]. In addition to that, it is often observed that, old manuscripts are subject to background damage [6]. It is common for such manuscript images to require specialized processing like image enhancement in order to remove background noise and make the image more legible. A potential additional benefit of such enhancement work could be its contribution towards developing effective printed, typewritten and handwritten Ethiopic character recognition system as image (pre) processing is useful when it comes to improving the quality of manuscript images before recognition [7] [8].

Image enhancement is among the sub-tasks of image processing. It is basically improving the interpretability or perception of information in images for human viewers and providing `better' input for other automated image processing techniques [9]. Image enhancement refers to accentuation, or sharpening of image features such as edges, boundaries, or contrast to make a graphic display more useful for display and analysis [9]. Image enhancement involves mainly two techniques; a histogram-modifying point operation or spatial digital filtering [10].

Point operations are, in general, simple nonlinear operations that are well known in the image processing literature while spatial operations used in image processing today are, on the other hand, typically linear operations [11]. Although linear image enhancement tools are often adequate in many applications, significant advantages in image enhancement can be attained if nonlinear techniques are applied. Nonlinear methods effectively preserve edges and details of images while methods using linear operators tend to blur and distort them [11].

An image may be of poor quality because its contrast is low, or it is noisy, or it is blurred [12]. Many algorithms have been devised to remove these degradations and enhance quality of the image. The difficult problem is how to remove degradations without hurting the signal describing the content of the image [12]. For example, noise-reduction algorithms typically involve local, averaging or smoothing which, unfortunately, will blur the edges in the image. Adaptive methods have been investigated, for instance, smoothing less near the edges. However, they are generally effective only if the degradation is slight. A challenging problem is then how to enhance severely degraded images. In addition to image degradation during photography or scanning of manuscripts, a noise can be introduced in the transmission medium due to a noisy channel, errors during the measurement process and during quantization of the data for digital storage. The image acquired at the receiving end needs processing before it can be used for further applications. To restore the original image at the receiver end is the challenging task for researchers [13]. Image enhancement methods are based on subjective image quality criteria and aims to develop an image quality metric that is well correlated with the human subjective scores [14]. For many years, researchers have primarily relied on synthetic noisy image for developing and evaluating image de nosier, but recently, more focus has been given to evaluating image de nosier on real noisy images [15].

1.2. Motivation

One great advantage of digital archives over analogue collection is that digital files may be read, reformatted, compressed, transferred and retrieved over computer networks [16]. It is made accessible and viewed on computer monitors. It can be accessed over the internet simultaneously by millions of users at different locations and beyond without degradation of the contents, and can also be copied limitless times with just a click of the computer mouse. Additionally it will help to avoid damage that can be caused to the original manuscripts through repeated handling. However, despite the availability of advanced photography and scanning equipment, natural aging and deterioration have rendered many manuscript images unreadable. In addition, the digital forms created from pictures and scanned manuscripts suffer from a number of limitations like blur, lighting condition, alignment, geometrical distortions and presence of noise [17].

Digital image processing techniques are necessary to improve the legibility of the manuscripts [18]. Also, digital image enhancement work is required to reduce the impact of the aforementioned effects while maintaining the authenticity and integrity of the original information. The effectiveness of such digital enhancement is highly dependent on the pre-processing techniques used. One of the ways of digital document enhancement is noise reduction (image filtering). There is critical need to identify the type of noise and explore effective noise reduction method(s) [17] [1].

1.3. Statement of the Problem

The Ethiopian National Archives and Library Agency (ENALA) is an institution established with the objective of collecting, organizing, maintaining the national information resources and avail them for study, research and referencing purposes [16]. Sizeable numbers of manuscripts of historical significance are kept by the agency. Some of them have suffered certain damage or have poor legibility and the scripts are difficult to read. These age-old manuscripts are not available for all, because of their delicate condition. To provide public access to these manuscripts efforts are underway to digitize such collections. It is observed that the quality and legibility of the digitized forms at times is low. Informal communication with the staff of the Ethiopian National Archives and Library Agency has revealed the presence of critical need to improve the quality of such digitized manuscript images. In addition to the damage in content, they might have sustained in the original materials, manuscript images may be contaminated with noise during transmission, scanning or conversion to digital form [1].

Noise reduction techniques are likely to improve the quality and readability of the digital documents. The effectiveness of noise filtering techniques may vary depending on the type of noise they are implemented upon. The nature of the noise removal problem depends on the type of the noise corrupting the image [19]. Each filter works differently on different types of noises [13]. Gedion [20] applied noise reduction techniques such as median, adaptive median and wiener filters for enhancing the performance of page segmentation. Further, Biruk [21] explored on restoration for retrieval of historical Amharic document images. Also Simon [22] conducted a study on hyperspectral imaging for readability enhancement of Historic manuscripts.

The choice of filtering technique is often determined by the nature of the task and the type and behavior of the image [23]. Therefore, the envisaged research attempts to explore and design appropriate noise reduction scheme to deal with degradation and noises observed in historical digitized manuscripts.

To this end, the study attempts to explore and answer the following research questions:

- What is the level of degradation found in digital images of historical manuscripts during image acquisition, coding, transmission, and processing?

- Which noise filtering technique is suitable for the enhancement of digital images of historic manuscripts?
- To what extent the designed noise filtering technique is effective in improving the quality of digital images of historic manuscripts?

1.4. Objective of the study

1.4.1. General Objective

The general objective of the study is to identify image enhancement techniques that improve the quality and legibility of selected digitized historic Amharic manuscript images.

1.4.2. Specific Objectives

To achieve the general objective of the research, the following specific objectives are formulated.

- To prepare data set of digital images of historic Amharic manuscripts for experimentation
- To identify common types and levels of noises existing in digitized manuscript images
- To compare various noise reduction techniques for their effectiveness for various types and levels of noises.
- To design a prototype for the selected appropriate noise reduction techniques that improve the quality of digitized manuscript images
- To evaluate and measure the performance of the prototype.

1.5 Methodology of the study

An exhaustive literature review work has been done by exploring various relevant literatures on the subject of this study. Sources which include research reports, journal and scientific articles, thesis, dissertation, books and additional sources available on web are reviewed. The literature review work helps to acquire detailed understanding of the subject of the study and formulate the methodology followed.

Accordingly, hereunder we define the step-by-step procedure followed and methods used for objectively achieving the objective of the study.

1.5.1. Research design

In this research we follow experimental research. Experimental research is a scientific approach to research, where one or more independent variables are manipulated and applied to one or more dependent variables to measure their effect on the latter. The effect of the independent variables on the dependent variables is usually observed and recorded over some time, to aid researchers in drawing a reasonable conclusion regarding the relationship between these two variable types [24].

In the current study enhanced digital images of historic documents is a dependent variable, while types of noises in digital images of historic documents are considered as independent variables. The improvement in the quality of the digital images with respect to noise reduction will be tested against the various noise reduction techniques. Experimental research is very important in comparing the efficiency of the noise reduction techniques with regard to digital images of historic manuscripts and help to identify appropriate procedures in the future.

To apply experimental research the study has to pass through dataset preparation (digital image acquisition and preprocessing in the current case), implementation of the prototype and evaluation (utilize and test the various noise reduction techniques). Broadly, using the same set of tests images, different image enhancement algorithms can be compared systematically to identify whether a particular algorithm produces better results [25]. Tasks done and methods used at each step are discussed as follows.

1.5.2 Dataset Collection and preparation

Selected historical manuscripts from the collections of Ethiopian National Archives and Library Agency (ENALA) are used to get digital forms through photography. The selection procedure is purposive in that manuscripts in diverse state of condition (good, medium or bad) can be represented. Images of manuscripts dating back to the early 20th century are taken by 8 and 16 mega pixels digital cameras. The manuscripts related to six letters written from the then Ethiopian heir of the throne, Teferi Mekonnen, to administrators of various areas of the country. The letters are written in Amharic with ink on paper. The digital images are colored and subjected to different noise reduction procedures, such as median filter, mean filter, Gaussian filter and morphological filters. The aim of using cameras of 8 and 16 mega pixels is to get images of varying quality so that the different noise reductions algorithms can be tested at different platforms.

There are age-old manuscripts of diverse and critical importance which are available in public archival collections. Access to original copies of these manuscripts to users is limited because of the fragile nature of the materials and the need for non-invasive way of access. In addition spatial limitations also hamper access. Availing digital copies addresses the limitations associated with these problems. Maintaining the quality of the digital images through preprocessing to improve readability and also suitability for further processing is an important step in the utilization of the manuscripts and the information contained in them. Noise introduced is among the common factors that would affect quality of digital images and applying preprocessing techniques would be important in improving the quality. Noise removal is one of the steps in pre-processing [1]. The aim of pre-processing is an improvement of the image data that suppresses undesired distortions or enhances some image features relevant for further processing and analysis task [26]. Image filtering deals with modifying image properties from pictures such as edges, corners, and blobs so as to enhance the quality of images.

The staff of the Ethiopian National Archives and Library Agency has revealed the critical need to improve the quality of digitized manuscript images (personal communication) and image pre-processing is one of the ways. In addition to the damage in image content that might have been sustained in the original materials, manuscript images may be contaminated with noise during transmission, scanning or conversion to digital form [1].

1.5.3 Implementation tools.

The study involves undertaking comparative study of different noise filtering algorithms for their efficiency in enhancing image quality. The MATLAB programming language is used in implementing the various filtering procedures and selection of the most suitable filtering technique(s). The selection of MATLAB is because of its good image processing ability. It has rich libraries for images processing such as noise removal (mean filtering and median filtering) and morphological analysis, which minimizes the time needed for the development of filtering tool [27].

1.5.4 Evaluation methods

Performance analysis is done to measure the efficiency by which image is recovered by a filtering technique. The performance of the various proposed filtering techniques are compared based on the values of Mean Squared Error (MSE), Peak Signal to Noise Ratio (PSNR) and Mean Absolute Error (MAE) [25]. The PSNR computes the peak signal-to-noise ratio, in decibels, between two images. This ratio is used as a quality measurement between the original and a compressed image. The higher the PSNR, the better the quality of the compressed or reconstructed image is. The MSE represents the cumulative squared error between the compressed and the original image. It is used to measure the closeness to the true or original value of the pixel with respect to the de-noised pixel compressed and the original image. The lower the value of MSE, the better the filtering algorithm removes noise in the image. The MAE is the absolute error between the original image and the de-noised image obtained after applying one of the filters. It is used to measure the closeness to the true or original value of the pixel with respect to the de-noised pixel [28] [29].

1.6 Scope and Limitation of the study

Large number and diverse types of manuscripts are found in various archives. In some cases allowing access to such original manuscripts may endanger their safety. In addition to that, some could be highly fragile. Under such condition transcribing the manuscripts to digital form should be mandatory. An added benefit of such digitization is improved access by users elsewhere. Despite the presence of large number and diverse manuscripts at various places and institutions, the proposed study envisages to address limited number of selected manuscripts (that are handwritten) at ENALA, which have historical significance. The study employs a group of noise reduction procedures as a pre-processing (enhancement) technique for the improvement of the quality and naturalness of document images.

The work doesn’t include images of printed and other graphics as they are out of the scope of the current study. Also the study doesn’t employ all possible image enhancement procedures as the plan is to implement selected most frequently used noise reduction techniques. There are manuscripts with a wide range of state of condition from those in very good condition to highly damaged images. Only image samples of manuscripts with different levels of quality and naturalness degradation are purposively used for designing prototype for image enhancement.

1.7 Significance of the study

The result of the study will contribute in identifying the right type of noise reduction method(s) on digitized manuscripts and provide recommendation on the type of method for the various types and levels of noise to be studied. This improves the quality and legibility of the digital forms of the manuscripts and may also contribute to the success of retrieval and character recognition. As the study contributes to enhancement of the quality of the digital images of the various manuscripts it improves the service delivery of ENALA and other institutions keeping manuscripts.

In addition to that, historians, researchers, academic and the general public can benefit from the study as more information can be obtained from enhanced images than unenhanced ones. The work also contributes to the knowledge base of processing of manuscripts. Further research directions will also be identified for researchers as a way forward to design an effective system for organizing, indexing, searching and accessing historical manuscripts.

1.8 Organization of the Study

This thesis is organized into five chapters. Chapter one includes the introduction where background information is given, while Chapter two is a literature review which includes an overview of the Image Filtering, Image Enhancement literature and related works done in the same area. Chapter three describes the proposed method of study in detail including the techniques and algorithms and the different Noise filtering procedures. Chapter Four emphasizes on presentation and discussion of the outcome and results of the comparative study. Conclusions and recommendations from the results of the study constitute Chapter five of the thesis.

CHAPTER TWO

LITERATURE REVIEW

It is common for archive libraries to provide public access to historical and ancient digital manuscript image collections [1]. Manuscripts aging from few decades to thousands of years are often in bad or damaged background [5]. As digital images of such manuscripts are widely shared and utilized, their quality is one of the concerns besides organizing and storing them well. The quality of digital images can be influenced or degraded by a number of factors that are either related to the original documents or noise introduced during the photographing or scanning process. As such, the image needs pre-processing to enhance its quality and before it can be used for further processing [30] [31]. Image de-noising, as a process which involves the manipulation of the image data to produce a visually high quality image, contributes a lot to removal of background noise and making the digital image more legible [1] [30]

2.1 What is a digital image?

An image is a two-dimensional function f(x,y), where x and y are the spatial (plane) coordinates, and the amplitude of f at any pair of coordinates (x,y) is called the intensity of grey level of the image at that point. When the x, y, and the intensity values of *f* are all finite, discrete quantities, we call the image a digital image [31]. Further, a digital image is an image composed of picture elements, also known as pixels, each with finite, discrete quantities of numeric representation for its intensity or gray level that is an output from its two-dimensional functions fed as input by its spatial coordinates denoted with x, y on the x-axis and y-axis, respectively. Depending on whether the image resolution is fixed, it may be of vector or raster type. By itself, the term "digital image" usually refers to raster images or bitmapped images (as opposed to vector images) [32]. In general, a digital image can be represented as follows:

$$\begin{bmatrix} f(1,1) & f(1,2) & \dots & f(1,N) \\ f(2,1) & f(2,2) & \dots & f(2,N) \\ \vdots & \vdots & & \vdots \\ f(N,1) & f(N,2) & \dots & f(N,N) \end{bmatrix}$$

with $1 \leq f(x, y) \leq N$, where usually N is expressed as positive integer, powers of 2 (N = 2n) [30].

2.2. Digital Image Processing

Image processing is a method to perform some operations on an image, in order to get an enhanced image or to extract some useful information from it [35]. There are two main types of image processing [35]: image filtering and image warping. Image filtering changes the range (i.e. the pixel values) of an image, so the colors of the image are altered without changing the pixel positions, while image warping changes the domain (i.e. the pixel positions) of an image, where points are mapped to other points without changing the colors [33]. Image processing is also a type of signal processing in which input is an image and output may be image or characteristics/features associated with that image [34]. Image Processing nowadays refers mainly to the processing of digital images [35].

Digital image processing refers to processing digital images by means of a digital computer [36]. Image Processing has been developed in response to three major problems concerned with pictures [35]:

- Picture digitization and coding to facilitate transmission, printing and storage of pictures;
- Picture enhancement and restoration to interpret pictures more easily;
- Picture segmentation and description as an early stage to Machine Vision.

2.3 Quality of an image

The quality of an image is a complicated concept, largely subjective and very much dependent on the effectiveness of applications. Basically, an image is of good quality when it is not noisy; not blurred; has high resolution and has good contrast [35]. A common objective for image acquisition in cultural heritage projects is to produce high quality images. Overall image quality is usually understood to mean the visual impression, and this can have many components such as sharpness and colorfulness, and personal preferences [37].

2.3.1 Meaning of Image noises

Noise represents unwanted information which deteriorates image quality and it is a random variation of image intensity and visible as grains in the image [38]. A noise is introduced in the transmission medium due to a noisy channel, errors during the measurement process and during quantization of the data for digital storage. Each element in the imaging chain such as lenses, film, digitizer and others contribute to the degradation [30]. Noise is also introduced in digital artworks when scanning damaged surfaces of the originals [39].

Noise originates from the physical nature of detection processes and has many specific forms and causes [13]. Digital noise is generally caused by insufficient light levels at the site location. It may also occur when the imaging sensors come under the effect of environmental conditions at the time of image acquisition. Another cause is heat, the image sensor heats up causing photons to get separated from the photo-sites and taint other photo-sites. A very slow shutter speed allows the noise to enter. Presence of dust particles on the scanner screen and the presence of inference in the transmission channel can also corrupt the image [40]. Noise manifests itself in the digital image in a random uncorrelated manner, making it inescapable to degrade the visual quality of the images besides harshly limiting the precision and accuracy of image interpretation and examination [41].

2.3.2 Types of Image noises

Noise is always present in digital images during image acquisition, coding, transmission, and/or processing steps [41]. There are diverse types of noises, of which the common types are Salt and Pepper Noise, Poisson Noise, Gaussian Noise and Speckle Noise [13, 40].

Salt and Pepper Noise

Salt and Pepper Noise is also called data drop noise because statistically it results in drop of the original data values (see figure 2.1). However, the image is not fully corrupted by salt and pepper noise instead some pixel values are changed in the image [42]. It is caused by sensor and memory problems due to which the pixels are assigned incorrect maximum values [43].The image characteristic is deblurring [42].

Figure 1. An image with salt and pepper noise [42]

Gaussian Noise

It is also called as electronic noise because it arises in amplifiers or detectors. As shown in figure 2.2, the Gaussian noise affects both the dark and light areas of an image [43]. It is statistical noise having a probability density function (PDF) equal to that of the normal distribution, which is also known as the Gaussian distribution. In other words, the values that the noise can take on are Gaussian-distributed. Principal sources of Gaussian noise in digital images arise during acquisition. In digital image processing Gaussian noise can be reduced using a spatial filter, though when smoothing an image, an undesirable outcome may result in the blurring of fine-scaled image edges and details because they also correspond to blocked high frequencies. Conventional spatial filtering techniques for noise removal include: mean (convolution) filtering, median filtering and Gaussian smoothing [42, 44].

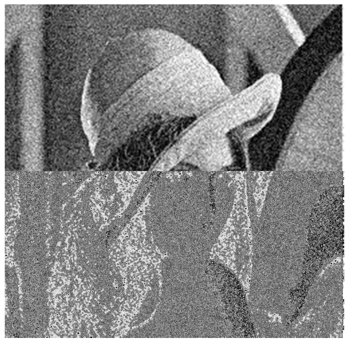


Figure 2. An image with Gaussian noise [39]

Speckle Noise

Speckle noise is multiplicative noise unlike the Gaussian and salt pepper noise which are additive [45]. Speckle noise is commonly found in synthetic aperture radar (SAR) images, satellite images and medical images [46]. Speckle noise degrades the image quality [47]. It is caused by coherent processing of backscattered signals from multiple distributed targets [13]. Figure 2.3 shows an image degraded by speckle noise. Speckle noise reduction techniques were found to enhance Ultrasound Sound images as well as Synthetic Aperture Radar (SAR) imagery [46].

Figure 3. An image with Speckle noise [42]

Poisson Noise

Poisson Noise, is known as a shot noise, follows distribution, which is closely related to Gaussian distribution (see figure 2.4). This kind of noise shows when the numbers of photons present in an image that are captured with the sensors are seemingly not strong enough to pin point statistical fluctuations in a particular measurement [42]. The appearance of this noise is seen due to the statistical nature of electromagnetic waves such as x-rays, visible lights and gamma rays. The x-ray and gamma ray sources emitted number of photons per unit time. These rays are injected in patient's body from its source, in medical x rays and gamma rays imaging systems [48].

Figure 4. An image with Poisson noise [39]

2.3.3. Source manuscript conditions

Quite often manuscripts could be of different conditions. Variations old documents may occur because of damage to the background caused by varying contrast, smudges, dirty background, ink through page, outdated paper and uneven background. Sometimes, the documents have contrast problems such as the foregrounds are usually having damaged ink with different background color [6]. Thin / thick / consistent stroke pen width texts, multiple touching characters, badly blurred or missing ink broken characters with holes or light handwriting, characters with different colours (e.g. red) ink, poor quality of ink etc. are also found to cause differences in the condition of manuscripts [77] and images of such manuscripts are likely to present different levels of difficulty to detect characters [6] and process. Sitti et al. [6] categorized images from manuscripts with higher and lesser levels of difficulty to detect characters as bad and medium, respectively. Dimitrios et al. [77] has also used quality of paper, brightness of the aging paper, the level of deterioration of colours over the years, the contrast between foreground and background characters, the quality of ink, presence of broken characters, and characters with holes or light handwriting as a basis for evaluating the condition of manuscripts.

2.3.4 Noises in Historical Manuscript Images

Among libraries, and museums, there are old documents such as historical manuscripts preserved in storage areas (see figure 2.5). Many of these documents are considered as quite important for national heritage. Document images may be contaminated with noise during transmission, scanning or conversion to digital form to provide public access to historical and ancient document image collections. Noises are one of the most common degrading factors which affect the visibility of the images and make them unclear. The main noises found in manuscripts are pepper and salt noise, speckle noise and holes on billings etc. [49].

(a) (b)

Figure 5. Images of manuscripts with different noises (Source (a) [50] (b) [51])

2.4 Steps in Digital Image Processing

Image processing basically includes the following three steps [26]. The first step is importing the image via image acquisition tools. The next step is analyzing and manipulating the image. The final step is generating an output in which result can be altered image or report that is based on image analysis. There are two types of methods used for image processing; namely, analogue and digital image processing [34]. Analogue image processing can be used for the hard copies like printouts and photographs. Digital image processing techniques help in manipulation of the digital images by using computers [54].

Image preprocessing is the first stage of detection to improve the quality of images, removing the irrelevant noises and unwanted parts in the background of the skin images [52] and is an important step in which the noise and other undesirable content will be removed [53]. The preprocessing of an image is used for the recognition of characters from the image. Preprocessing is done to increase the quality of the image required to allow the steps following it to deliver accurate results [27]. Digital image processing consists of the manipulation of images using digital computers. The processing of digital images can be divided into several classes, such as image enhancement, image restoration, image analysis and image compression [36].

Image enhancement

Image enhancement is basically improving the interpretability or perception of information in images for human viewers and providing `better' input for other automated image processing techniques. The principal objective of image enhancement is to modify attributes of an image to make it more suitable for a given task and a specific observer. During this process, one or more attributes of the image are modified [9]. The two important examples of image enhancement are: increasing the contrast and changing the brightness level of an image so that the image looks better [55].

Image restoration

Digital image restoration is a field of engineering that deals with methods used to recover an original scene from degraded observations [56]. Digital Image restoration attempts to reconstruct or recover an image that has been degrading using a prior knowledge of the degradation phenomenon. The purpose of image restoration is to “compensate for” “or undo” defects which degrade an image [57]. Restoration techniques aim at processing corrupted images from which there is a statistical or mathematical description of the degradation, so that it can be reverted [36]. Digital image restoration is a very broad field and contains many triumphant approaches that have been developed from different perspectives, such as optics, astronomy, and medical imaging [56].

Image enhancement and restoration are used to process degraded or blurred images [34].

2.4.3. Image Analysis

Image analysis is the extraction of meaningful information from images; mainly from digital images by means of digital image processing techniques. Image analysis tasks can be as simple as reading bar coded tags or as sophisticated as identifying a person from their face. Computers are indispensable for the analysis of large amounts of data, for tasks that require complex computation, or for the extraction of quantitative information [58]. Image analysis techniques permit that an image be processed so that information can be automatically extracted from it. The tasks of image analysis are image segmentation, feature extraction and classification [36].

Image segmentation is the process of partitioning an image into multiple partitions, so as to change the epitomization of an image into something that is more meaningful and easier to analyze [59].

Feature extraction is a part of the dimensionality reduction process, in which, an initial set of the raw data is divided and reduced to more manageable groups. These features are easy to process, but still able to describe the actual data set with the accuracy and originality [60].

Image classification actually, refers to the task of extracting the information classes from a multiband raster image. It analyzes the numerical properties of various image features and organizes the data into the different predefined categories [61].

2.5. Image filtering techniques

Image filtering is the process of removal of noise from image [63]. In order to recover original image with better quality and naturalness, there is a need to remove noise. Hence the concept of image filtering is introduced. Image filtering is not only used to image quality but it is a process aimed at selectively extracting certain aspects of image that are considered to convey important information in the context of a given application [40]. Filters are meant for reduction of the amount of unwanted noise and reversal of the effects of blurring in a particular image [63].

There are so many filtering algorithms available in the literatures that are used for filtering images [64]. They are classified into Linear vs. Nonlinear filtering algorithms; Low psss vs. High pass filtering as well as Spatial vs Frequency domain filtering.

2.5.1 Linear and Non-linear filtering

2.5.1.1 Linear filtering

Linear filters are used as the primary tools for many of the signal and image processing applications, because of the availability of systematic theory for design and analysis [65]. Linear filters also tend to blur sharp edges, destroy lines and other fine image details, and perform poorly in the presence of signal-dependent noise [19]. A linear operation sets each pixel to the average value, or a weighted average, of itself and its nearby neighbors [19]. Under the linear filters category we find mean filter (along its variations such as harmonic mean filter, Contra-harmonic mean filter etc.) adaptive mean filter, Gaussian filter and wiener filter [13][66]. Generally linear model are being considered for image de-noising. The main benefit of using linear noise removing models is the speed, and the limitation of the linear models is the models are not able to preserve edges of the images in an efficient manner. Non-linear models can preserve edges in a much better way than linear models but are very slow [67]. Linear filters are often used to remove noise and distortion that was created by nonlinear processes, simply because the proper non-linear filter would be too hard to design and construct [68].

2.5.1.2 Non-linear filtering

Nonlinear filtering is a well -known noise filtering and edge -preserving method. This class of filters has become popular in digital speech and image processing and has achieved some interesting results in many image processing applications [69]. In signal processing, a non-linear filter is a filter whose output is not a linear function of its input. Non-linear filters have many applications, especially in the removal of certain additive types of noises. For example, the median filter is widely used to remove spike noise — that affects only a small percentage of the samples, possibly by very large amounts [68]. In Non-linear filtering the output is not a linear function especially in the removal of certain types of noise that are not additive or cannot be done with convolution or Fourier multiplication. All digital signal processing depends on non-linear filters (analog-to-digital converters) to transform analog signals to binary numbers. Nonlinear filters are considerably harder to use and design than linear ones, because of the most powerful mathematical tools of signal analysis [68]. Within the non-linear group we find median and, morphological filters. Generally even if linear methods are fast enough in removing certain type of noise, they do not preserve the details of the images, and we need to use non- linear methods to preserve the details of the images.

2.5.2 Low Pass vs. High Pass Filtering

Low pass and High pass filters are performing convolution between two array sets which are image elements and filtering mask. By this property low-pass and high-pass filters are good to use in image transformation.

2.5.2.1. Low Pass Filtering

Highly suitable filters that could be used for digital image filtering require good edge and image details preservation properties. Most of the digital images require low-pass filtering. Low pass filtering tends to blur edges and destroy lines, edges, and other fine image details. It is employed to remove high spatial frequency noise from a digital image. The most simple low-pass filter is the ideal low-pass. It suppresses all frequencies higher than the cut-off frequency D_0 and leaves smaller frequencies unchanged:

$$H(k,l) = \begin{cases} 1 & if \sqrt{k^2 + l^2} < D_0 \\ 0 & if \sqrt{k^2 + l^2} > D_0 \end{cases}$$

In most implementations, D_0 is given as a fraction of the highest frequency represented in the Fourier domain image [64]. The steps include the following [70]:-

Step 1: Input – Read an image

Step 2: Saving the size of the input image in pixels

Step 3: Get the Fourier Transform of the input image

Step 4: Assign the order n and cut-off frequency D_0

Step 5: Designing filter: Low Pass Filter

Step 6: Convolution between the Fourier Transformed input image and the filtering mask

Step 7: Take Inverse Fourier Transform of the convoluted image

Step 8: Display the resultant image as output.

2.5.2.2 High Pass Filtering

High pass filters are basically used to make the image appear sharper. High pass filtering works in exactly the same way as low pass filters but uses the different convolution kernel and it emphasizes on the fine details of the image [71]. High pass filtering is used to edge enhancement or edge detection. High pass filter can improve the image by sharpening; however, overdoing of this filter can actually degrade the image quality [71]. A high pass filter function by inverting the corresponding Low-pass filter. The steps include the following.

Step 1: Input – Read an image

Step 2: Saving the size of the input image in pixels

Step 3: Get the Fourier Transform of the input image

Step 4: Assign the Cut-off Frequency D0

Step 5: Designing filter: Ideal High Pass Filter

Step 6: Convolution between the Fourier Transformed input image and the filtering mask

Step 7: Take Inverse Fourier Transform of the convoluted image

Step 8: Display the resultant image as output.

Generally, high pass frequency components denote edges whereas the low pass frequency components denote smooth regions. The results would be different as, the low pass reduces the edged content and the high-pass increases it [72].

2.5.3. Spatial vs. Frequency domain filtering

Denoising filtering methods are in spatial or in frequency domain. Difference between spatial domain and frequency domain is that, in spatial domain, we deal with images as it is. The value of the pixels of the image changes with respect to scene. Whereas in frequency domain, we deal with the rate at which the pixel values are changing in spatial domain [9]. High frequencies result in a smoother image in the spatial domain, attenuating low frequencies enhances the edges [66].

Spatial filtering deals with the image pixels. The pixel values are manipulated to achieve desired enhancement. In a spatially filtered image, the value of each output pixel is the weighted sum of neighboring input pixels. The weights are provided by a matrix called the convolution kernel or filter. The simplest spatial domain operations occur when the neighborhood is simply the pixel itself [9].

In frequency domain filtering, the image is first transferred in to frequency domain. It means that, the Fourier Transform of the image is computed first. All the enhancement operations are performed on the Fourier transform of the image and then the Inverse Fourier transform is performed to get the resultant image. These enhancement operations are performed in order to modify the image brightness, contrast or the distribution of the grey levels. As a consequence, the pixel value (intensities) of the output image will be modified according to the transformation function applied on the input values [9].

2.6. Challenges in Image Enhancement

Image processing is a dynamic and fast moving field of research. It is mainly composed of Image enhancement and restoration techniques which are designed to improve the quality of an image as perceived by a human. Recent advances in the area have led to an explosion in the use of images in a variety of scientific and engineering applications [73]. New approaches are constantly being developed by mathematicians, engineers and computer scientists to be applied to image processing problems [34]. The use of image processing techniques has become almost ubiquitous; they find applications in such diverse areas as astronomy, archaeology, medicine, video communication, and electronic games [12].

Nonetheless, many important problems in image processing remain unsolved [12]. There are many computational challenges in image processing. These include issues such as the handling of image uncertainties that cannot be otherwise eliminated, including various sorts of information that is incomplete, noisy, imprecise, fragmentary, not fully reliable, vague, contradictory, deficient, and overloading. However, some computational techniques such as fuzzy logic, neural networks, and evolutionary methods have shown great potential to solve such image processing problems [73].

Challenges in image processing happen in the process of Compression, Enhancement, Recognition and Visualization [12]. Compression of an image with a very large signal to an image of small signal without significant loss of image quality is among major challenges of image processing. Similarly enhancing image quality by removal of degradation without hurting the signal; recognition when the number of classes is very large; and ensuring realistic visualization models at a reasonable cost are critical challenges which need to be surmounted in image processing [12].

The process of the enrolment or capturing of images faces a number of challenges ranging from unequal resolutions, format variations, non-uniform illuminations, distortions and noise. Other external issues are variations in orientation and contrast. In most cases, these challenges prompt the implementation of enhancement algorithms prior to usage [74].

As images are widely shared and utilized their quality will be very important. The quality of image can be influenced or degraded by a number of factors. The lack of sharpness and presence of noise can have effect on the image quality. Noise is one of the most common factors and it can significantly affect visual quality of images, as well as the performance of most image processing tasks [18]. There are diverse type of noises of which the common types are Salt and Pepper Noise, Poisson Noise, Gaussian Noise and Speckle Noise [13, 67]. In addition to that, the noise can be of different intensities where the level could vary between images. Efficiency of various filters in denoising different noises of digital images varies [75] and there is a need for identification of appropriate denoising filters for each type and level of noises.

2.7. Related works

In the past, a number of researches have been conducted on various aspects of digitized documents world-wide. We reviewed foreign and local research works to assess problem explored, approach followed, results achieved and further research directions so as to identify research gaps for further study.

2.7.1. Foreign works

Simon [22] has applied hyperspectral and multispectral imaging techniques on historic manuscripts to enhance the legibility of faded or deliberately removed writings. In this study pre-processing which included noise reduction and spectral sharpening have also been employed. In this work, the high versatility of hyperspectral imaging for legibility enhancement of historic manuscripts was confirmed. The technique provides a toolset for various issues and can be adapted to the diverse objects that are expected in this field of application, like the separation of different, overlaying scriptures or the attenuation of disturbing background effects [22].

Ganchimeg [1] has proposed a hybrid binarization approach for improving the quality of old documents using a combination of global and local thresholding. He has also reviewed noises that might appear in scanned document images and discussed some noise removal methods. The proposed approach is able to deal with hard cases while maintaining precision on a high level and suggested for use by libraries willing to provide public access to their historical document collections, as well as a preprocessing step in document image analysis systems.

Dimitrios et al. [77] have presented sequential image processing procedures which were applied for image refinement and enhancement on quality class categorized images of historical (i.e. Byzantine, old newspapers, etc.) manuscript. They reported that, compared to the image enhancement method, the image classification method is more text / image characteristic-oriented and highly depends on the historical document to be investigated. As such there is no ideal method working for every case and a single suitable method that can be applied to all types of images.

Li and Yao [78] have worked on Image inpainting aspect which is the process of filling in missing parts of damaged images based on information gleaned from surrounding areas, and they have presented two variational models for image inpainting. The experimental results show the effective performance of the proposed models in restoring scratched photos, text removal, and even removal of entire objects from images. They concluded that by combining two models, it is possible to simultaneously fill in missing, corrupted or undesirable information, while removing noise.

2.7.2. Local works

There are different researches conducted using Amharic documents of diverse types [8] [27] [20] [21] [79]. Biniam [94] has evaluated three noise reduction (or filtering) techniques, explicitly median, wiener, adaptive median filters in combination with Otsu, Niblack and Sauvola thresholding algorithms. The performance results obtained show that the combination of wiener filtering and Otsu thresholding had achieved the highest peak signal-to-noise ratio (PSNR) of 68.2106 dB for low level, 65.2637 dB for medium level, 60.6395 dB for high level and 58.949 dB for very high level noisy printed Amharic real-life document images. Similarly, Shiferaw [79] has applied adaptive, median, mean and bi-level (first adaptive and mean filter next) noise filtering techniques as a preprocessing procedure for Optical Character Recognition (OCR) for Gee'z scripts written on the vellum. The result obtained has shown that the bi-level noise filtering method has produced the best result than the other three noise filtering methods and for subsequent work and further processing the researcher has used the de-noised image produced through bi-level noise filtering method [79]. From his work on optical character recognition of typewritten amharic text [95] has found inefficiency of applying specific filters to specific images, rather he suggested development of an optimal filter for images with similar properties.

Alula [27] has studied pre-processing of mobile captured document images and among his recommendations stands out the presence of need to research on a pre-processing of digital document images. From three noise removal techniques, based on the experiment, Wiener filter with 1.92 MSE and 48.99 PSNR and from three binarization techniques, Sauvola with 0.13 MSE and 57.62 PSNR were found to perform best with the highest PSNR and lower MSE. The challenges in the study are detecting correctly the text region and non-text region under diverse document conditions and further study was recommended in these regard.

Biruk [21] has researched restoration and retrieval of historical Amharic document images and recommended the need for pre-processing to realize improved restoration and address issues of document effects such as skewness. In this study different images restoration techniques were experimented, such as Dilate, Erode and Combination of Mathematical Morphology techniques as well as Haar, Daubechies, and Symlet wavelet techniques on historical documents as well as real life documents. Performance analysis shows that best result is obtained by combining mathematical morphology with Otsu thresholding. Finally, the performance of the restoring systems on retrieval has shown an improvement of retrieval effectiveness by 4.65% F-measure. Unavailability of standardized corpus was identified as major challenge and preparation of a standardized corpus was suggested for use on experimentation in similar studies.

2.8. Research gap

The first task that must be done in order to manipulate and process images is digitization. After digitization, the next vital process in document analysis is to perform pre-processing on this image to prepare it for further analysis [21]. Past research works on document images as pertains to image restoration, retrieval and extraction to improve the quality and use of digitized documents, have also stressed the need for pre-processing of images to address defects in the original documents and those that exist in scanned or photographed digital images. Reduction of noise as pre-processing activity causes spatial features of digital images become sharper and richer in contrast and contributes to improved quality of digital images. The collection of digital images of manuscripts of importance do need some level of pre-processing to improve their quality. Appropriate de-noising procedures need to be identified for the various types and levels of degradation of the digital images of the manuscript collections. This research work attempts to address problems related to noises affecting image quality of selected historic manuscripts and identify and establish appropriate noise filtering procedures for various types and levels of noises that may affect the quality of digital images of manuscripts of importance.

CHAPTER THREE

METHODS AND ALGORITHMS

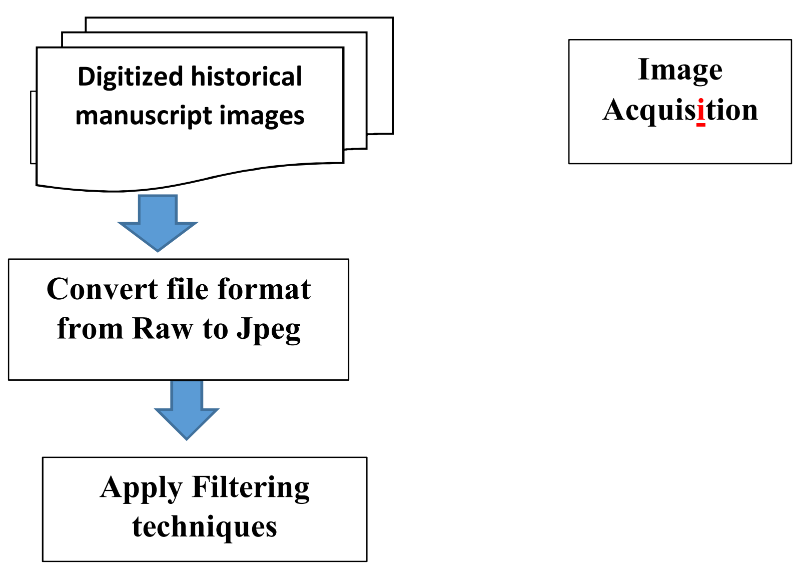
3.1. Overview

Manuscripts of historic and religious importance are maintained by different archives, libraries and repositories. Due to their high importance and delicate nature, in most cases, non-invasive way of utilizing the manuscripts for diverse purposes (research, education, tourism etc..) is critical. Digital images are the major means of availing the documents while keeping the original hard copies safe. The Ethiopian National Archives and Library Agency (ENALA) has a large collections of manuscripts with age ranging from few decades to a number of centuries. Effort is under way to digitize and make the digital images available to users. Quality of the images of the manuscripts is an issue because of the damage caused on the manuscripts as a result of aging or poor handling or noise introduced during digitizing.

A number of researchers have studied diverse digital enhancement methods to improve qualities of images of documents [7, 9, 10, 11, 12, 21, 79]. Except Biruk [21] who worked on enhancement and retrieval of images of Amharic manuscripts and Shiferaw [79] who dealt with optical character recognition for Gee'z Scripts written on the Vellum, the others have dealt with printed documents. Biruk [21] and Shiferaw [79] also suggest the need for better image restoration techniques to improve the performance of image recognition and retrieval. In the current study pre-processing of digital images of Amharic manuscripts of diverse condition through noise removal is undertaken with a goal of developing optimal procedure of denoising digital images for improved quality.

3.2 The Proposed Architecture

Figure 3.1 shows the proposed architecture for digital images enhancement of Amharic manuscripts. The initial stage was purposive sampling of manuscripts from the historic collections maintained by ENALA. In as much as possible way manuscripts of diverse conditions were selected. Two digital cameras; one with Images resolution capacity of 8 pixel and the other with 16 pixel were used and images were taken by each camera. The images were transferred from the Camera to a computer and various noise filtering algorithms were applied. The resulting images after filtering were compared for efficiency in reducing noise and improving picture quality using different parameters such PSNR () and MSE ().



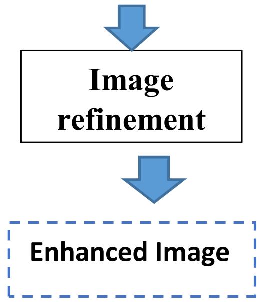


Figure 6. Proposed Architecture for image enhancement

3.2.1 Data set of digitized historical manuscript images

This study was based on six sets of digital images of original Amharic manuscripts where each set contains image taken by 8 and 16 megapixel digital Cameras. The Amharic manuscripts belong to ENALA's collection of historical manuscripts and are letters written in ink by the then heir to the throne Ras Teferi Mekonnen to a number of local administrators. All letters were written during the early twentieth century. All images were in JPG (Joint Photographic Group) format.

3.3. Image filtering algorithms

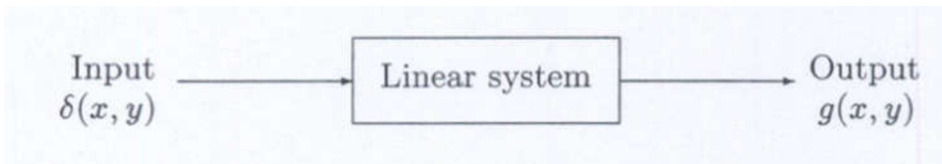
Noise removal or denoising is one of the pre-processing steps that contribute to image enhancement. In this study an attempt is made to apply noise removal techniques, in order to restore digital images of manuscripts obtained from photographing of historical Amharic manuscripts in various conditions.

A variety of algorithms i.e. linear and nonlinear are used for filtering images. Linear filters are used as the primary tools for many of the signal and image processing applications, because of the availability of systematic theory for design and analysis [7]. Generally linear model are being considered for image denoising. The main benefits of using linear noise removing models is the speed and the limitations of the linear models is the models are not able to preserve edges of the images in an efficient manner in non-linear models can preserve edges in a much better way than linear models but are very slow [67]. In the current study the filters within the linear category namely: Mean filter and Gaussian filter were used while within the non-linear group the median, and the morphological filters were used.

3.3.1. Linear Filters

The most common, simplest and fastest kind of filtering is achieved by linear filters. Many image processing operations can be modeled as a linear system [18]

The linear filter replaces each pixel with a linear combination of its neighbors and convolution kernel is used in prescription for the linear combination. The simplest linear filter to implement is known as the mean filter.



3.3.1.1. Mean filter

Mean Filter performs average smoothing on an image. The name perfectly describes the function of this filter. Each pixel in I (image) is replaced with the mean of the pixels that surround it. Especially, noise is blended into the rest of the picture. A filter that performs average smoothing must use a kernel with all entries being non-negative.

The idea of mean filtering is simply to replace each pixel value in an image with the mean (`average') value of its neighbors, including itself. This has the effect of eliminating pixel values which are unrepresentative of their surroundings. Mean filtering is usually thought of as a convolution filter. There are different types of mean filter and these include arithmetic mean filter, geometric mean filter, harmonic mean filter and contraharmonic mean filter [31]. One of the simplest linear filters is implemented by a local averaging operation where the value of each pixel is replaced by the average of all values in the local neighborhood:

$$h[i,j] = \frac{1}{M} \sum_{(k,l)\in N} f[k,l]$$

where M is the total number of pixels in the neighborhood N [80].

Let I be an image of size N, m is an odd number smaller than N, and A is the kernel of a linear filter, that is a mask of size m. Additionally, it is absolutely necessary for all the entries in the kernel to have a sum of one. If the sum is not equal to one, then the kernel must be divided by the sum of the entries (hence the multiplication of the 1/3). For example, if a kernel A = [1 1 1] was used with m (size) = 3: Aavg = 1/3 [1 1 1] which is $[\frac{1}{3}\ \frac{1}{3}\ \frac{1}{3}]$. If the requirement is not met, then the filtered image will become brighter than the original image, along with undergoing the specified filtering effect. This limitation on the mean filter fulfills the seconded portion of the image filtering goal which being effective at attenuating noise because averaging removes small variations. The effect is identical to that of averaging a set of data to help reduce the effect of outliers. In a two-dimensional mean filter, the effect of averaging m^2 noisy values around pixel divides the standard derivation of the noise by $\sqrt{m^2}$ =m(size) [63].

3.3.1.2. The Gaussian filtering

Gaussian filters are a class of linear smoothing filters with the weights chosen according to the shape of a Gaussian function. The Gaussian smoothing filter is a very good filter for removing noise drawn from a normal distribution. The Gaussian filtering scheme is based on the peak detection. The peak detection is based on the fact that peaks are to be impulses. The key point is that this filter corrects not only the spectral coefficient of interest, but all the amplitude spectrum coefficients within the filter window. Some properties of Gaussian filter are 1. The weights give higher significance to pixels near the edge there by reducing edge blurring [5].

A typical noise model is the Gaussian (or normal) distribution parameterized by π and σ which is computed using the following formula.

$$p(x) = \frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$$

3.3.2. Non-Linear Filter

3.3.2.1. Median Filter

An important non-linear filter that will preserve the edges and remove impulse noise is standard median filter [7]. Median filter is widely used in impulse noise removal methods due to its denoising capability and computational efficiency. However, it is effective only for low noise densities. To overcome this drawback, many recent techniques first detect the impulse locations and then filter the noisy pixels without processing the uncorrupted ones. Specialized median filters such as weighted median filter, center weighted median filter and Recursive Weighted Median Filter (RWMF) were proposed to improve the performance of the median filter by giving more weight to some selected pixel in the filtering window [7].

The median is determined by first sorting all the pixel values from the window into numerical order, and then reinstate the pixel being weighed with the middle (median) pixel value [81].

The main problem with local averaging operations is that they tend to blur edges in an image. An alternative approach is to replace each pixel value with the median of the gray values in the local neighborhood of that pixel. Filters using this technique are called median filters.

In order to perform median filtering in a neighborhood of a pixel [i.j], there are two steps to apply:

1. Sort the pixels into ascending order by gray level.
2. Select the value of the middle pixel as the new value for pixel [i.j]

The median filter's hardware implementation is straightforward and does not require many resources. This filter is used traditionally to remove impulse noise as it is the most popularly used non-linear filter. The standard median filter does not perform well when impulse noise is greater than 0.2 [96]. A simple median filtering utilizing 3×3 or 5×5-pixel window is sufficient only when the noise intensity is less than 20% [97]. When the intensity of noise is increasing, a simple median filter leaves many shots unfiltered. This filter does not preserve detail and it also smoothen non-impulsive noise.

3.3.2.2. Morphological filter

Morphological filter is a collection of non-linear operations related to the shape or morphology of features in an image. As noted in [82] morphological operations rely only on the relative ordering of pixel values, not on their numerical values, and therefore are especially suited to the processing of binary images. Morphological operations can also be applied to grey scale images such that their light transfer functions are unknown and therefore their absolute pixel values are of no or minor interest. It is an effective noise reduction algorithm for Salt and pepper type of noise [82].

Morphological techniques probe an image with a small shape or template called a structuring element. The structuring element is positioned at all possible locations in the image and it is compared with the corresponding neighborhood of pixels. Some operations test whether the element ”fits” within the neighborhood, while others test whether it ”hits” or intersects the neighborhood [83]. A structuring element is simply a binary image that allows us to define arbitrary neighborhood structures. The structuring element is a small binary image, i.e. a small matrix of pixels, each with a value of zero or one. The matrix dimensions specify the size of the structuring element. The pattern of ones and zeros specifies the shape of the structuring element [83].

Morphological filters (Minimum and maximum filters), also known as erosion and dilation filters, respectively, are filters that work by considering a neighborhood around each pixel. From the list of neighbor pixels, the minimum or maximum value is found and stored as the corresponding resulting value. Finally, each pixel in the image is replaced by the resulting value generated for its associated neighborhood. If we apply max and min filters alternately they can remove certain kind of noise, such as salt-and-pepper noise very efficiently [13].

The most basic morphological operations are dilation and erosion. Dilation adds pixels to the boundaries of objects in an image, while erosion removes pixels on object boundaries. The number of pixels added or removed from the objects in an image depends on the size and shape of the structuring element used to process the image. In the morphological dilation and erosion operations, the state of any given pixel in the output image is determined by applying a rule to the corresponding pixel and its neighbors in the input image. The rule used to process the pixels defines the operation as a dilation or erosion [83].

Erosion removes pixels on object boundaries. In other words, it shrinks the foreground objects and enlarges foreground holes while the effects of Dilation are the opposite of Erosion and adds pixels on object boundaries and fill the holes in the foreground and enlarge foreground objects [85]. Erosion and dilation are dual morphological operations which cause a reduction or enlargement in the size of regions respectively [86].

For dilation, the result is the maximum value of the value in H adds to the current sub-image.

$$(I \oplus H)(u,v) = \max_{(i,j)\in H} \{I(u+i, v+j) + H(i,j)\}.$$

For erosion, the result is the minimum value of the difference.

$$(I \ominus H)(u,v) = \min_{(i,j)\in H} \{I(u+i, v+j) - H(i,j)\}.$$

These operations can cause negative value, so we need to clamp the result after calculation [87].

3.4. Convolution and Kernel size

Convolution is a specialized type of linear operation used for feature extraction, where a small array of numbers, called a kernel, is applied across the input, which is an array of numbers, called a tensor [88]. Therefore kernel size is a number specifying both the height and width of the (square) convolution window [89].

Many research methods for restoration or denoising have been proposed over years including those which consists of moving a kernel over each pixel in the spatial image and applying a mathematical function on this neighborhood of pixels by replacing the central pixel of the kernel with the computed function value [90].

The same author [90] has studied the effect of the kernel size of two main filters, namely Gaussian filter and Wiener filter, on their performance evaluation through computer simulations applied to several images corrupted with Gaussian noise and speckle noise [90]. The optimal kernel size depends on the filtering algorithm [90] [91]. In general, larger kernels would remove more noise from the image, but they will also mean more undesirable artifacts such as blurring out edges [92].

3.5. Performance evaluation

With the presence of diverse filtering techniques it is important to measure the efficiency of each filtering method in improving image quality.

3.5.1. Mean Square Error:

The Mean Square Error (MSE) symbolizes your cumulative squared mistake relating to the compacted along with the unique image.

$$MSE = \frac{1}{mn} \sum_{0}^{m-1} \sum_{0}^{n-1} \| f(i,j) - g(i,j) \|^2$$

Where *f* represents the matrix data of our original image, *g* represents the matrix data of our degraded image, m represents the numbers of rows of pixels of the image and *i* represent the index of that row, *n* represents the number of columns of the pixels of the image and *j* represents the index of that column.

3.5.2 Peak signal-to-noise ratio:

The Peak Signal to Noise Ratio (PSNR) is the value of the noisy image with respect to that of the original image. This ratio is often used as a quality measurement between the original and a compressed image. The higher the PSNR, the better the quality of the compressed or reconstructed image would be.

$$PSNR = 20\log_{10}\left(\frac{MAX_f}{\sqrt{MSE}}\right)$$

Here MAX_f is the maximum signal value that exists in our original image.

3.5.3 Mean absolute error

Mean absolute error (MAE) measures the average magnitude of the errors in a set of predictions, without considering their direction. It's the average over the test sample of the absolute differences between prediction and actual observation where all individual differences have equal weight. MAE is defined as the maximum absolute value, the difference between original image and degraded image [93]

$$\mathrm{MAE} = \frac{1}{n}\sum_{j=1}^{n}|y_j - \hat{y}_j|$$

CHAPTER FOUR

EXPERIMENTAL RESULT AND DISCUSSION

4.1. Overview

This study has attempted to enhance the image quality of historical manuscripts through use of different image noise filtering methods which are likely to provide different results when used on images of manuscripts under varying condition. It is believed to make contribution in identifying appropriate noise reduction procedures for organizations or individuals who provide access to digital images of historical manuscripts. The enhancement contributes towards improvement of the quality and legibility of digitized historic Amharic manuscripts and may also improve character recognition in retrieval of information from the digitized manuscripts. As such the image enhancement improves the service delivery of ENALA and other institutions keeping manuscripts. Six manuscripts of historical importance have been purposively selected among the manuscript collections of ENALA. The purposive selection was necessary to ensure that manuscripts which are under varying condition (good, medium, poor) can be represented and the enhancement can be tested under varying environment. Subjective judgment was used to classify the manuscripts into good, medium and poor condition. Manuscripts which are legible and where the edges of each character is clearly discerned are classified as good while manuscripts with relatively less legibility and some blurring of the edges of some of the characters are classified as in a medium condition. Manuscripts where there is difficulty in identifying most of the characters are classified as in poor condition.

For the experimentation (testing different noise filtering methods) a Hewlett-Packard (HP) laptop computer with specification Intel (R) Core(TM)i5-2520M CPU @ 2.5GHz 2.50 GHz, installed RAM of 4.00 GB and 64-bit operating system, x64-based processor was used. The operating system used was Windows 10 professional edition Version 20H2. MATLAB R2018a Version 9.4.0.813654 image processing tool was used for image processing.

4.2. Dataset preparation

Six pairs of digital images of the manuscripts were acquired through use of digital cameras with 8 and 16 megapixel resolutions with the assumption of getting images of different quality per manuscript (Appendix 1). Eight megapixel was considered a lower range, if need be, for acceptable enlarged printing of the enhanced image while doubling the megapixel was assumed to provide adequate variation to test the impact of image resolution on the result of filtering and quality of image to be obtained upon filtering. Images Set 1 and Set 2 are obtained from manuscripts in good condition, images Set 3 and Set 5 from manuscript in poor condition while images 4 and 6 are from manuscripts rated as in a medium condition. Each set has two images (Set 1-1, Set 1-2, Set 2-1 and Set 2-2 ….Set 6-1 and Set 6-2) one taken with a resolution of 8 mega pixel while the other is taken with resolution of 16 megapixel. The images were transferred from the Cameras to a computer and each image was given identification code (Table 4.1) and various noise filtering algorithms were applied.

Table 1 Identification of the images used in the experimentation

Manuscript No.	Condition of Manuscript	Image Resolution in megapixel	Image code
Set 1-1	Good condition	8	DSCO-4086
Set 1-2	Good condition	16	IMG_2955
Set 2-1	Good condition	8	DSCO-4087
Set 2-2	Good condition	16	IMG_2953
Set 3-1	Poor condition	8	DSCO-4088
Set 3-2	Poor condition	16	IMG_2951
Set 4-1	Medium condition	8	DSCO-4095
Set 4-2	Medium condition	16	IMG_2957
Set 5-1	Poor condition	8	DSCO-4092
Set 5-2	Poor condition	16	IMG_2946
Set 6-1	Medium condition	8	DSCO-4090
Set 6-2	Medium condition	16	IMG_2947

4.3. Experimental results

Linear (Mean and Gaussian) and non-linear (median and morphological) filtering algorithms are used. The morphological filter used was of two types: dilation and erosion. All the filters were tested at kernel size of 3 by 3 and 5 by 5. A total of 120 MATLAB procedures are conducted (6 manuscripts X 2 resolutions X 5 filtering algorithms X 2 kernel size). The resulting images after filtering were compared for efficiency in reducing noise and improving picture quality using different parameters (PSNR, MSE, MAE) and subjective judgment.

4.3.1. Effect of Filtering Methods on the first set of images from manuscript in good condition

The result of image filtering algorithms obtained from the first set of images (Set 1-1 and Set 1-2) taken from manuscripts in good condition is shown in Table 4.2.

Table 2. Results of filtering algorithms for manuscript images in good condition

Filtering algorithm	Set 1-1			Set 1-2		
	PSNR	MSE	MAE	PSNR	MSE	MAE
Mean filtering (3,3)	19.1402	9.6615	0.7699	18.5330	12.7783	0.7281
Mean filtering (5 ,5)	17.5661	19.9463	1.1362	17.0627	25.1497	1.1546
Median Filtering[3 3]	21.6382	3.0580	0.4509	20.2541	5.7843	0.5211
Median Filtering [5 5]	19.8926	6.8323	0.6375	18.7646	11.4857	0.8514
Gaussian Filtering[3]	16.7761	28.6985	1.4937	16.5541	31.7878	1.3520
Gaussian Filtering [5]	14.8088	71.0097	2.3628	15.1440	60.8517	1.8300
Dilation [3]	12.8905	171.7862	0	12.8821	172.4523	0
Dilation [5]	11.3547	348.4506	0	11.6498	304.1690	0
Erosion [3]	12.5993	196.4384	8.2301	12.8298	176.6540	7.3825
Erosion [5]	10.8295	443.7842	12.6297	11.3746	345.2690	10.8979

As shown in Table 2, Median filtering has resulted in the best filtering outcome as judged by all parameters (PSNR, MSE and MAE). Next to the Median filtering, the Mean filtering, Gaussian filtering, Morphological dilation and Morphological erosion have shown, in the respective order, descending values of PSNR, and ascending values of MSE and MAE implying corresponding decline in filtered image quality. With the exception of MAE values in few cases where the order of magnitude of the parameters show difference in the second best image, similar trend was observed for the PSNR, MSE and MAE of all images from manuscripts in the different conditions and the various filtering methods considered in this study. Though the trend in all the parameters is similar, the morphological filters have resulted in very high MSE values as compared to the mean, Median and Gaussian filters at different kernel size.

Figure 7 and 8 show strong relationships between PSNR and MSE as well as PSNR and MAE for the first set of images with 0.77 and 0.79 coefficient of determination, respectively. Correlations between the parameters for all the images were also found to be very strong with all values being above 0.87 (Appendix 2). As such the other tables (except images of set 1) which show all the parameters for the different filtering algorithms are put at the end (Appendix 3). Because of the similar trend in PSNR, MSE and MAE the interpretation on the results in the ensuing parts was mainly done based on PSNR values alone. For all images filtering with morphological dilation, despite repeated attempt, has resulted in a zero MAE value and excluded from the comparison and calculation of relationship between the parameters.

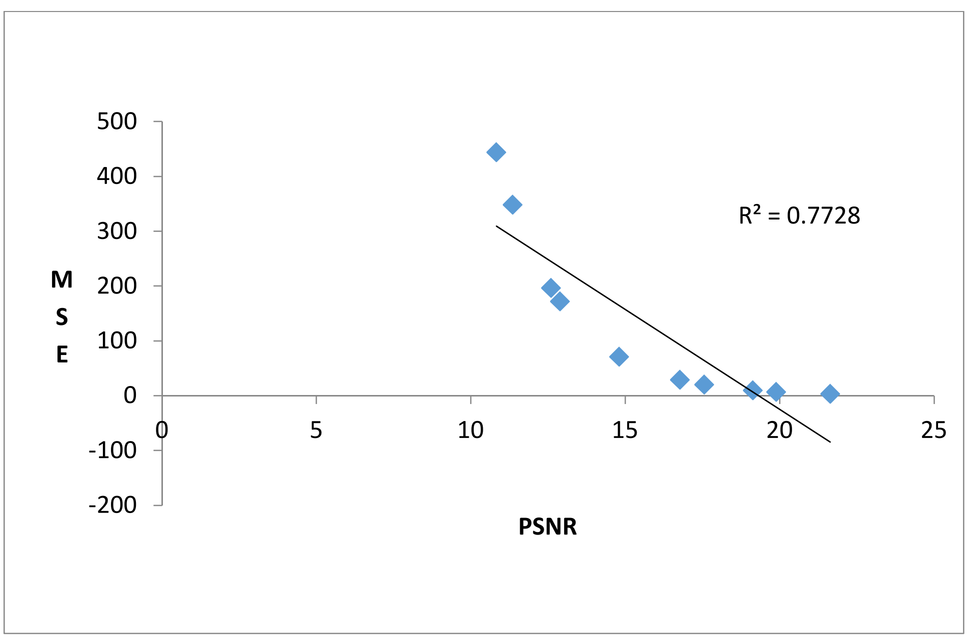


Figure 7.. Relationship of PSNR and MSE values form filtering of 12 images

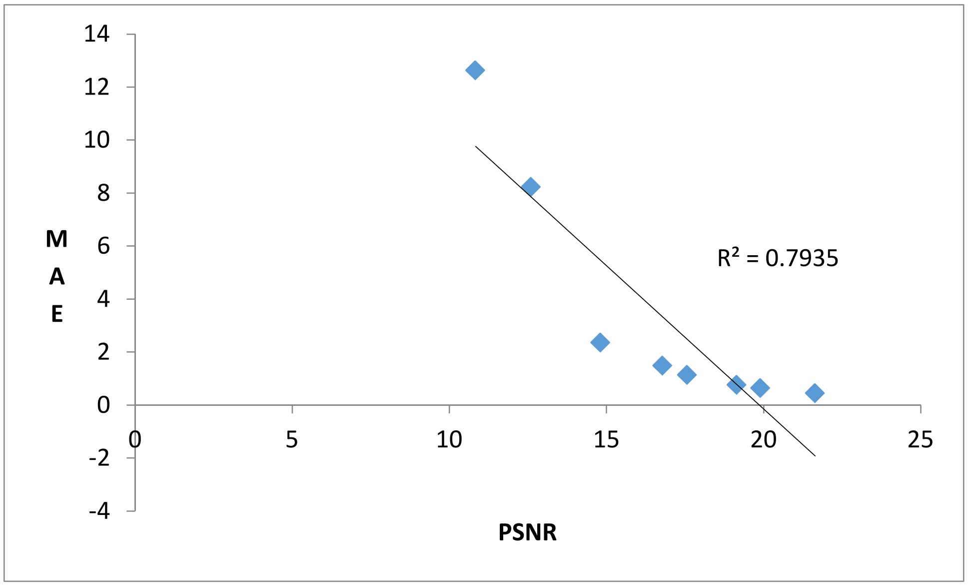
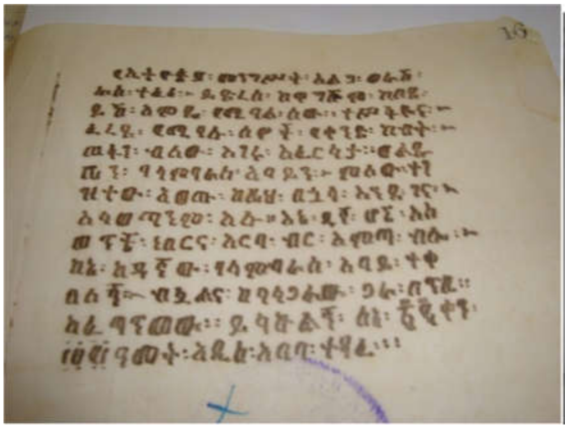
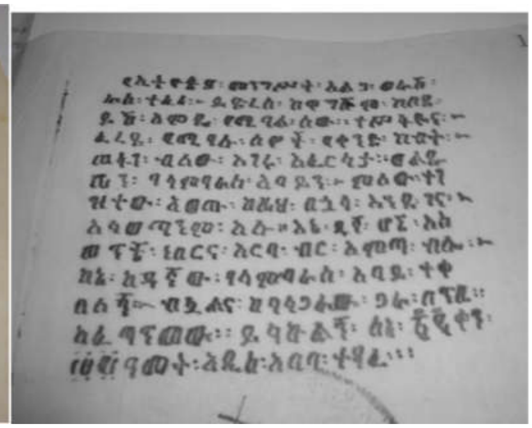


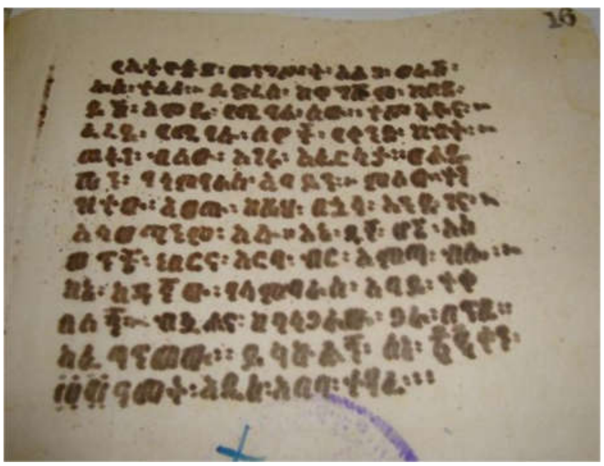
Figure 8. Relationship between PSNR and MAE for the images filtered using mean, median, Gaussian and morphological erosion filters

Images of the first manuscript (set 1.1.) before and after filtering are shown in Figure 9. Subjective evaluation between filtered images shows, despite the presence of sizeable differences in PSNR, MSE and MAE the images after filtering have not shown significant improvement when seen visually. However the best image (b) obtained after median filtering at 3 by 3 kernel size has improved the contrast between the letters and the background while the worst image obtained by morphological erosion filter at kernel size of 5 by 5 has thickened the characters and negatively affected the contrast and has also blurred the edges. In addition to that median filtering has caused change in the background color.





(a) (b)



(c)

Figure 9. Results of filtering algorithm on Good condition manuscript images; (a) The original image with 8 megapixel resolution; (b) Result of the best performing Median filtering algorithm; (c) Result of the worst performing Morphological erosion filtering .

4.3.2. Image filtering for images of manuscripts in different conditions

For all images obtained from manuscripts in good, medium and bad condition the median filter has shown the best performance with the highest values of PSNR (Table 3 and 4). For the images from one of the manuscript in poor condition and for both images from manuscript in medium condition the mean filter has given the second best result. The PSNR values do not appear to be dependent on the condition of the manuscript and values for images from manuscripts in good and poor condition, in most cases, have been higher than the values for images from manuscripts in medium condition. But some inconsistent result has been found for images obtained at a resolution of 16 megapixels. For the mean and median filtering comparable PSNR values were obtained for images from manuscripts of different condition.

Table 3. Peak Signal to Noise Ratio (PSNR) values obtained from the different filtering algorithms for images obtained from manuscripts in good, medium and bad condition with a 8 megapixel resolution

Condition of Manuscript	Filtering algorithm									
	Mean		Median		Gaussian		Morphological Dilation		Morphological erosion	
	3 by 3	5 by 5	3 by 3	5 by 5	3 by 3	5 by 5	3 by 3	5 by 5	3 by 3	5 by 5
Good	19.1402	17.5661	21.6382	19.8926	16.7761	14.8088	12.8905	11.3547	12.5993	10.8295
Good	19.2117	17.6665	21.5230	19.8377	16.9874	15.1182	13.0876	11.5421	12.8903	11.1851
Medium	18.4012	16.6561	19.8065	17.9127	15.6991	14.1121	12.0775	10.7398	11.7923	10.2542
Medium	18.4640	16.6266	19.6243	17.4816	15.9769	14.8348	13.1056	12.2467	11.9845	10.4483
Poor	19.3851	17.8945	21.7246	20.0529	17.0566	14.9215	12.7082	10.9612	12.5868	10.7563
Poor	19.6147	17.9653	20.8290	19.1192	16.9754	15.4587	13.6254	12.4834	13.0343	11.4662

Table 4. Peak Signal to Noise Ratio (PSNR) values obtained from the different filtering algorithms for images obtained from manuscripts in good, medium and bad condition with a 16 megapixel resolution

Condition of Manuscript	Filtering algorithm									
	Mean		Median		Gaussian		Morphological Dilation		Morphological erosion	
	3 by 3	5 by 5	3 by 3	5 by 5	3 by 3	5 by 5	3 by 3	5 by 5	3 by 3	5 by 5
Good	18.5330	17.0627	20.2541	18.7646	16.5541	15.1440	12.8821	11.6498	12.8298	11.3746
Good	18.5679	17.1214	20.3850	18.9432	16.5807	15.1191	12.9383	11.7059	12.9257	11.4945
Medium	18.2173	16.5992	19.8739	18.1787	15.7254	14.2937	12.0984	10.8099	12.0749	10.6196
Medium	18.4761	16.8172	20.2184	18.3691	15.9189	14.6091	12.6357	11.5997	12.3821	10.9219
Poor	18.2428	16.7965	19.8726	18.4287	16.4075	15.1213	12.6034	11.3378	12.6270	11.2012
Poor	18.2185	16.5863	19.7349	17.9849	15.7632	14.4515	12.2924	11.1463	12.1709	10.7423

4.3.3. Filtering of images with different resolution

Filtering of images taken at resolution of 8 and 16 megapixels have shown slightly different PSNR value where in most cases images taken at a resolution of 8 megapixels has resulted better PSNR values than images taken at a resolution of 16 megapixels. This is to be expected since the images with 16 megapixel resolutions are likely to be a good quality compared to images from 8 megapixel resolutions and consequently less effect of filtering. However, for images in medium condition the PSNR values in most cases (in 8 cases for the first image and in 6 cases in the second image from manuscripts in medium condition) the 16 megapixel has shown better PSNR values than images from 8 megapixel resolution (Table 5). For both images from manuscripts in good condition and from one of the manuscripts in poor condition for the Gaussian, morphological dilation and erosion at 5 by 5 kernel size have shown better values of PSNR for images from 16 megapixel resolution.

Table 5. Peak Signal to Noise Ratio (PSNR) values obtained from the different filtering algorithms for images of 8 and 16 Megapixel resolution

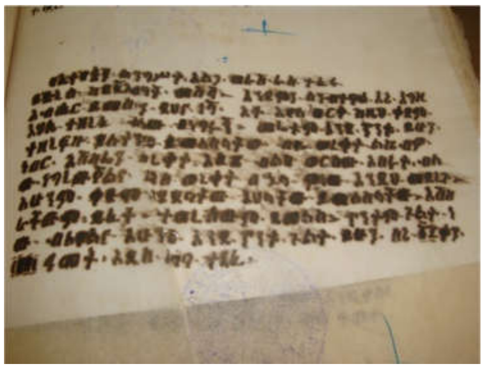
		Kernel size			
		3 by 3		5 by 5	
		Resolution in megapixels			
Image code	Filtering algorithm	8	16	8	16
Set 1	Mean	19.1402	18.5330	17.5661	17.0627
	Median	21.6382	20.2541	19.8926	18.7646
	Gaussian	16.7761	16.5541	14.8088	15.1440*

	Morphological-dilation	12.8905	12.8821	11.3547	11.6498*
	Morphological Erosion	12.5993	12.8298*	10.8295	11.3746*
Set 2	Mean	19.2117	18.5679	17.6665	17.1214
	Median	21.5230	20.3850	19.8377	18.9432
	Gaussian	16.9874	16.5807	15.1182	15.1191*
	Morphological-dilation	13.0876	12.9383	11.5421	11.7059*
	Morphological Erosion	12.8903	12.9257	11.1851	11.4945*
Set 3	Mean	19.3851	18.2428	17.8945	16.7965
	Median	21.7246	19.8726	20.0529	18.4287
	Gaussian	17.0566	16.4075	14.9215	15.1213*
	Morphological-dilation	12.7082	12.6034	10.9612	11.3378*
	Morphological Erosion	12.5868	12.6270*	10.7563	11.2012*
Set 4	Mean	18.4012	18.2173	16.6561	16.5992
	Median	19.8065	19.8739*	17.9127	18.1787*
	Gaussian	15.6791	15.7254*	14.1121	14.2937*
	Morphological-dilation	12.0775	12.0984*	10.7398	10.8099*
	Morphological Erosion	11.7923	12.0749*	10.2542	10.6196*
Set 5	Mean	19.6147	18.2185	17.9653	16.5863
	Median	20.8290	19.7349	19.1192	17.9849
	Gaussian	16.9754	15.7632	15.4587	14.4515
	Morphological-dilation	13.6254	12.2924	12.4834	11.1463
	Morphological Erosion	13.0343	12.1709	11.4662	10.7423
Set 6	Mean	18.4640	18.4761*	16.6266	16.8172*
	Median	19.6243	20.2184*	17.4816	18.3691*
	Gaussian	15.9769	15.9189	14.8348	14.6091
	Morphological-dilation	13.1056	12.6357	12.2467	11.5997
	Morphological Erosion	11.9845	12.3821*	10.4483	10.9219*

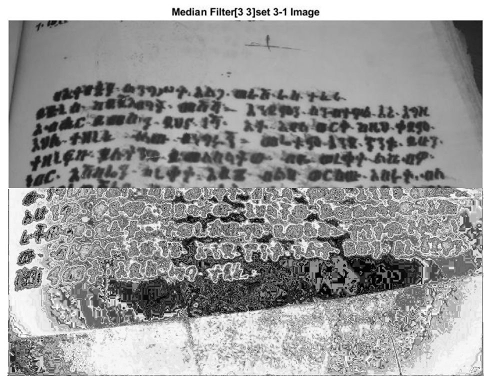
*Values where 16 megapixel images have shown higher PSNR values than 8 megapixel images

4.3.4. Effect of kernel size on filtered image quality

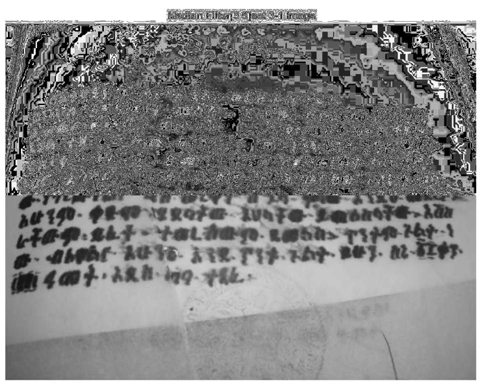
Increase in kernel size from 3 by 3 to 5 by 5 has resulted in lower PSNR (Tables 3, 4 & 5) and higher MSE and MAE, implying less efficiency of filtering at higher kernel size (Appendix 3). As is the case in the median filtering, for each filtering algorithm used in the current study, the 3 by 3 kernel size has shown better performance in filtering than the 5 by 5 kernel size. Despite change in the contrast, subjective evaluation of one of the images from a manuscript in poor condition does not appear to show observable improvement in image quality including legibility (Figure 10) which is tantamount to the difference in PSNR.



(a)



(b)



(c)

Figure 10. Original image of an image from manuscript with poor condition (a) after median filtering using kernel size of 3 by 3 (b) and 5 by 5 (c)

4.4. Discussion of result

In this study the median filtering algorithm was found to be the best among all the filtering methods tested. Similar superior performance of the Median filter for Salt & Pepper noise over the Mean filter has been reported by Pawan et al.[75]. In a comparative study made by Sanjib et al. [98] which involved Median filter, Gaussian filter, Kuan filter, Morphological filter, Homomorphic Filter, Bilateral

Filter and wavelet filter, it was found that Wavelet based filter gives the best result amongst the chosen filtering techniques. As opposed to the findings in the current study Alka [99] has compared Morphological, Averaging & Median Filter and found out that the morphological filter to be better than median and averaging filtering techniques. Obviously the type of images, the type and intensity of noise affecting the image can have effect and may account for the different results obtained. In the current study visual observation of the original and the filtered image has indicated that there is no clear improvement in image quality despite differences in the parameters. Even if the images appear to have no improvement, it should be noted that restoration of images operation which results in images that appear much worse than the original ones might still be satisfactory operation for some applications such as autonomous machine recognition or generally in applications where the main concentration is on the gross aspects of the image [90]. Until other method of filtering which is superior is tested and proved effective, median filtering algorism can be used to improve the quality of images of historical manuscripts which are under similar condition to the ones used in the current study.

Strong correlations between the parameters (PSNR, MSE and MAE) have been observed in this study. No other similar work was found in the literature. However, Verislav et al. [100] have reported almost identical (but opposite) correlation values for PSNR, MSE and MAE with radiologists' image quality ratings scores implying the similarity of the magnitude of the parameters.

The result in the current study shows, overall the effect of filtering algorithms on images from manuscripts in different conditions do not appear to be condition dependent and similar algorithms can be effective across images from manuscripts in diverse condition. In a condition where bad and medium condition manuscripts were considered, Sitti et al. [6] have suggested working on the medium quality manuscript and extending the methods to handle images from more challenging manuscripts.

In this study there are no substantial differences between images taken at 8 and 16 megapixel resolution. A higher megapixel count doesn't always equate to a better picture [101]. This implies that the resolution of images may not be a decisive factor in quality of digital images as long as there is no need for printing such images. However if there is need for printing of such images resolution may have effect on printed photos [101], particularly for enlarged pictures where dot per inch is important to influence quality. No literature was found which relates image resolution with efficiency of filtering for noise.

A kernel size of 3 by 3 is found to be better than the 5 by 5 as evaluated by the parameters. Similar findings to the current study where better filtering effect was obtained at a 3 by 3 kernel size for Gaussian filtering than 5 by 5, 7 by 7 and 9 by 9 kernel size has also been reported by Zayed [90]. However the same author has shown that Wiener filter shows poor performance when using the smallest kernel size (3x3) and to obtain a similar performance to that of the Gaussian filter in Wiener filtering, a larger kernel size is required which produces much more blur in the output mage. It appears that the optimal kernel size depends on the filtering algorithm [90] [91]. In general, larger kernels would remove more noise from the image, but they will also mean more undesirable artifacts such as blurring out edges [92].

CHAPTER FIVE

CONCLUSION AND RECOMMENDATION

5.1. Conclusion

This study has been carried with the objective of testing the efficiency of different filtering algorithms under different conditions in enhancing the quality of digital images of historical manuscripts. Six manuscripts (two from each of manuscripts in good, medium and poor condition) from the Ethiopian National Archives and Library Agency (ENALA) were used and two digital images from each manuscript were taken one at 8 megapixels and the second at 16 megapixel resolution.

Five image filtering algorithms namely: mean, median, Gaussian, Morphological dilation and morphological erosion were used to filter the images at 3 by 3 and 5 by 5 kernel size. MATLAB software was used for the filtering process and PSNR, MSE and MAE were used as parameters of evaluation. For the most part similar trend and strong correlation (negative for PSNR and the other two and positive for MSE and MAE) were observed for the three parameters.

Experimental results show that, median filtering is found to be the best filtering algorithm as judged by the parameters. The efficiency of filtering by the filtering algorithms has shown decline in the order of mean, Gaussian, morphological dilation and morphological erosion. Subjective evaluation from visual observation has not shown clear improvement in the filtered images but substantial change in the background color, contrast and edge blurring was observed for some of the images. The effect of condition of the original manuscripts was found to be inconsistent and the PSNR values do not appear to be dependent on the condition of the manuscript and values for images from manuscripts in good and poor condition, in most cases, have been higher than the values for images from manuscripts in medium condition. Increased image resolution from 8 to 16 mega pixels, in the most cases, has not shown improvement in efficiency and this is expected as less improvement is expected from images of high resolution upon filtering. However for some of the images (mainly images from manuscripts of medium condition) images from 16 megapixels resolution have shown higher values of PSNR and lower values of MSE and MAE as opposed to the expectation. Kernel size used for the different image filtering algorithms has shown difference where 3 by 3 kernel size has shown better filtering effect as compared to 5 by 5 kernel size. In addition to that the 5 by 5 kernel size has shown edge blurring effect for some of the images.

The result form this study indicates that images from manuscripts in different condition can be processed using similar procedures and differential filtering methods may not be necessary. The difference in condition of the manuscripts used appears to be of low level to cause various responses during processing. Additionally, the magnitude of the resolution of images may not have substantial effect on the results of filtering and a level of resolution of 8 or more megapixels can be used. However for some images of manuscripts may need to be printed and under such conditions higher level of resolution may need to be considered. Of the filtering algorithms used in the study consistently superior result was observed for the median filter and this filtering method can be recommended until other filtering methods which are more efficient are tested and recommended. Morphological dilation and erosion filtering have shown the least improvement and this filtering methods should be avoided from use for improving images of manuscripts similar to those used in the current study. Kernel size of 3 by 3 can be used and there is no need for higher kernel size for filtering of images. This study has focused on image enhancement using image filtering methods and has not considered other additional image restoration procedures.

5.2. Recommendation and future works

Based on the result obtained in this study, we recommend the following as a continuation of the current study

- In this study an attempt is made to experiment some of the filtering methods widely used by scholars. However to come up with a better manuscript image enhancement, there is a need to test more filtering algorithms both in spatial and frequency domain.
- This study has a great contribution towards designing and developing an effective image recognition and retrieval system. Hence we suggest an integration of image enhancement and image restoration to come up with an applicable system
- Image resolution levels considered in this study are 8 and 16 megapixels. Currently cameras (including mobile phones) with much higher resolution capacity are being developed. Therefore we suggest further investigation on

the effect of very higher levels of resolution on the efficiency of image enhancement.

- Filtering of images using different two different kernel size has been covered in the current study. Higher levels of kernel size under the various filtering algorithms are worth investigation.

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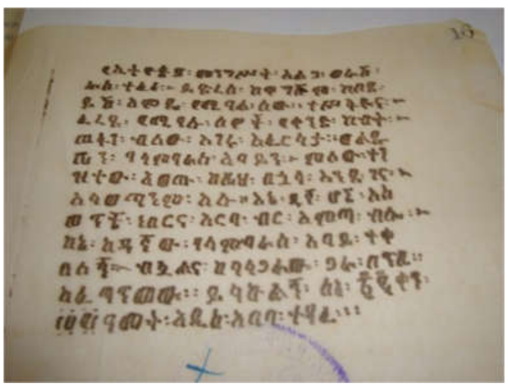
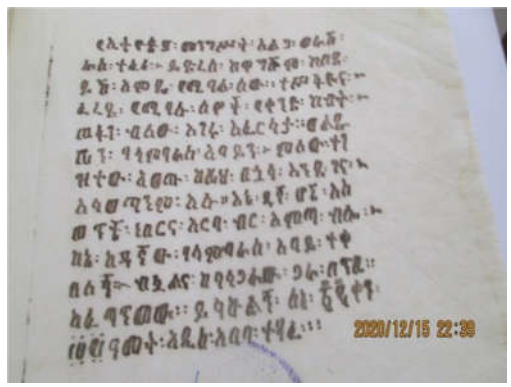
Appendix 1. Original Images of manuscripts used in the study

Set 1 (Good condition)

8 Megapixels

16 mega pixels

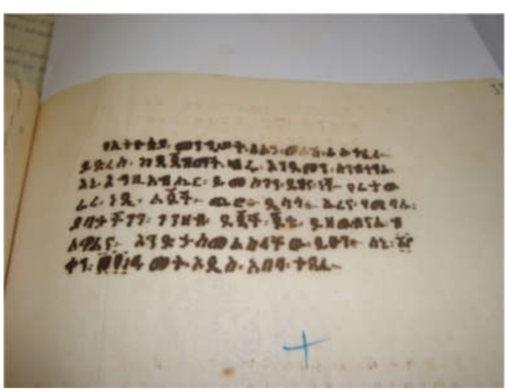


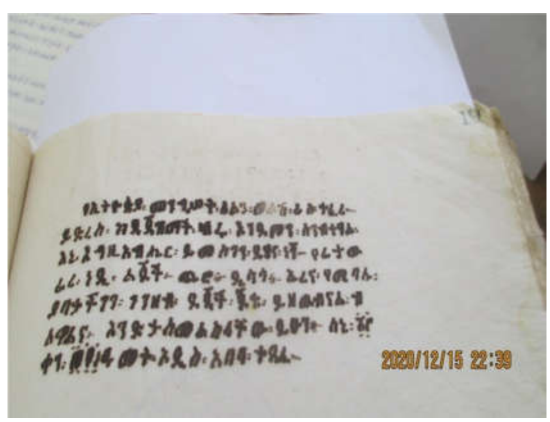


Set 2 (Good condition)

8 Megapixels

16 mega pixels

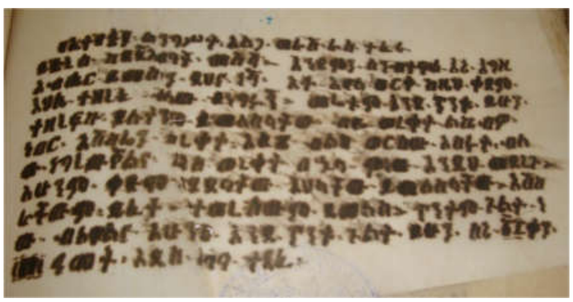


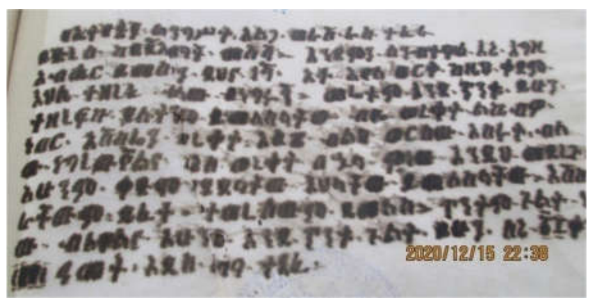


Set 3 (Poor condition)

8 Megapixels

16 mega pixels

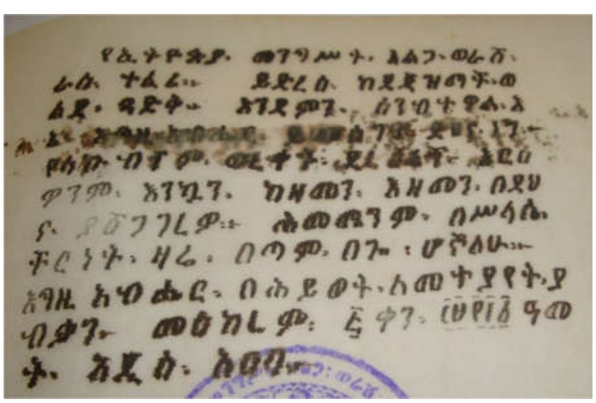


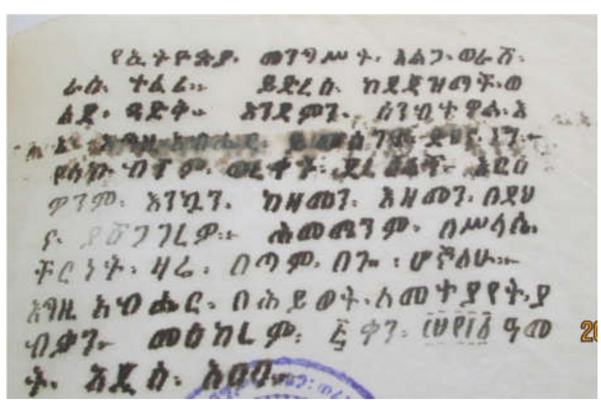


Set 4 (Medium condition)

8 Megapixels

16 mega pixels

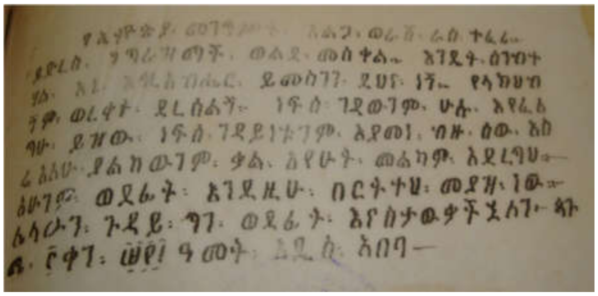


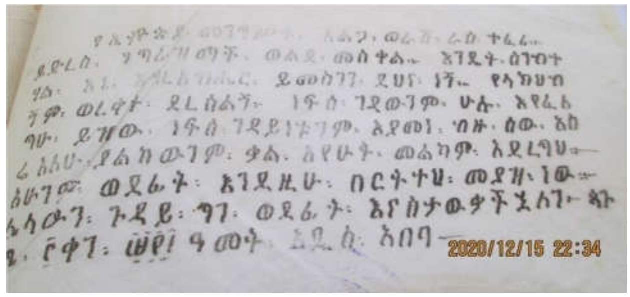


Set 5 (Poor condition)

8 Megapixels

16 mega pixels

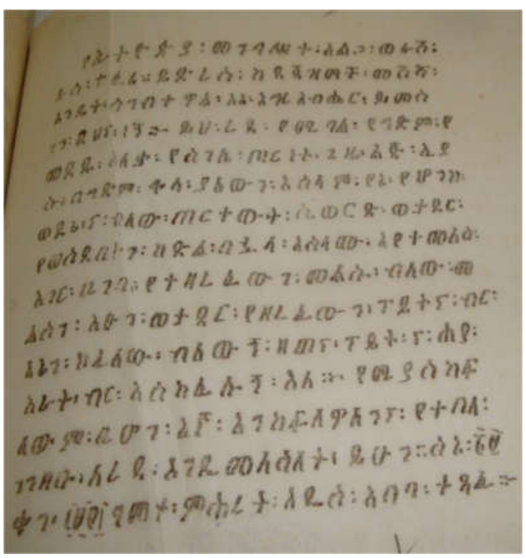


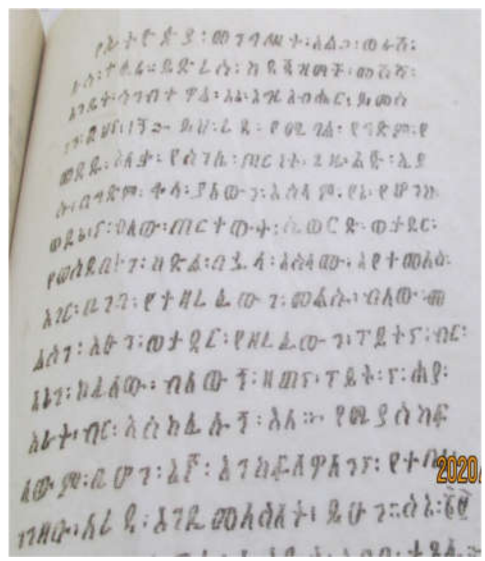


Set 6 (Medium condition)

8 Megapixels

16 mega pixels





Appendix 2. Correlations between Parameters

Table 1. Correlation between the parameters obtained from filtering of images using the various filtering algorithms

Image	PSNR-MSE	PSNR-MAE	MSE-MAE
set1-1	-0.879	-0.891	0.984
set1-2	-0.917	-0.905	0.989
set2-1	-0.889	-0.895	0.983
set2-2	-0.915	-0.900	0.988
se3-1	-0.882	-0.899	0.981
set3-2	-0.922	-0.912	0.990
set4-1	-0.904	-0.911	0.988
set4-2	-0.910	-0.901	0.989
set5-1	-0.897	-0.912	0.987
set5-2	-0.914	-0.903	0.989
set6-1	-0.880	-0.921	0.989
set6-2	-0.904	-0.897	0.989

Appendix 3. Parameter (PSNR, MSE, MAE) values for all images and filtering algorithms

Table A. 3.1. Parameter values for the set 1-1 and Set 1-2 images after filtering using the different algorithms.

Filtering algorithm	Set 1-1			Set 1-2		
	PSNR	MSE	MAE	PSNR	MSE	MAE
Mean filtering (3,3)	19.1402	9.6615	0.7699	18.5330	12.7783	0.7281
Mean filtering (5 ,5)	17.5661	19.9463	1.1362	17.0627	25.1497	1.1546
Median Filtering[3 3]	21.6382	3.0580	0.4509	20.2541	5.7843	0.5211
Median Filtering [5 5]	19.8926	6.8323	0.6375	18.7646	11.4857	0.8514
Gaussian Filtering[3]	16.7761	28.6985	1.4937	16.5541	31.7878	1.3520
Gaussian Filtering [5]	14.8088	71.0097	2.3628	15.1440	60.8517	1.8300
Dilation [3]	12.8905	171.7862	0	12.8821	172.4523	0
Dilation [5]	11.3547	348.4506	0	11.6498	304.1690	0
Erosion [3]	12.5993	196.4384	8.2301	12.8298	176.6540	7.3825
Erosion [5]	10.8295	443.7842	12.6297	11.3746	345.2690	10.8979

Table A 3.2. Parameter values for the set 2-1 and Set 2-2 images after filtering using the different algorithms.

Filtering algorithm	Set 2-1			Set 2-2		
	PSNR	MSE	MAE	PSNR	MSE	MAE
Mean filtering (5 ,5)	17.6665	19.0453	1.0705	17.1214	24.4790	1.0724
Mean filtering (3 ,3)	19.2117	9.3484	0.7423	18.5679	12.5746	0.6731
Median Filtering [3 3]	21.5230	3.2247	0.4757	20.3850	5.4460	0.4838
Median Filtering [5 5]	19.8377	7.0070	0.6583	18.9432	10.5788	0.7928
Gaussian Filtering [3]	16.9874	26.0379	1.2987	16.5807	31.4013	1.2352
Gaussian Filtering [5]	15.1182	61.5795	1.9294	15.1191	61.5534	1.6501
Dilation [5]	11.5421	319.6389	0	11.7059	296.4151	0
Dilation [3]	13.0876	156.8758	0	12.9383	168.0454	0
Erosion [3]	12.8903	171.8004	6.8529	12.9257	169.0211	6.4893
Erosion [5]	11.1851	376.7538	10.1976	11.4945	326.7300	9.4301

Table A.3.3. Parameter values for the set 3-1 and Set 3-2 images after filtering using the different algorithms.

Filtering algorithm	Set 3-1			Set 3-2		
	PSNR	MSE	MAE	PSNR	MSE	MAE
Mean filtering (5 ,5)	17.8945	17.1467	1.1775	16.7965	28.4306	1.2806
Mean filtering (3 ,3)	19.3851	8.6310	0.7986	18.2428	14.6053	0.8197
Median Filtering [3 3]	21.7246	2.9387	0.4716	19.8726	6.8954	0.5860
Median Filtering [5 5]	20.0529	6.3461	0.7159	18.4287	13.4071	0.9565
Gaussian Filtering [3]	17.0566	25.2212	1.5996	16.4075	34.0072	1.4708
Gaussian Filtering [5]	14.9215	67.4191	2.6002	15.1213	61.4936	1.9553
Dilation [5]	10.9612	417.6681	0	11.3378	351.1669	0
Dilation [3]	12.7082	186.8277	0	12.6034	196.0611	0
Erosion [3]	12.5868	197.5677	9.3122	12.6270	193.9454	8.4940
Erosion [5]	10.7563	460.2779	14.2068	11.2012	373.9720	12.5820

Table A.3.4. Parameter values for the set 4-1 and Set 4-2 images after filtering using the different algorithms.

Filtering algorithm	Set 4-1			Set 4-2		
	PSNR	MSE	MAE	PSNR	MSE	MAE
Mean filtering (5 ,5)	16.6561	30.3288	1.3911	16.5992	31.1350	1.2546
Mean filtering (3 ,3)	18.4012	13.5779	0.9191	18.2173	14.7782	0.7667
Median Filtering [3 3]	19.8065	7.1086	0.5875	19.8739	6.8913	0.5502
Median Filtering [5 5]	17.9127	17.0035	0.8806	18.1787	15.0431	0.9278
Gaussian Filtering [3]	15.6991	47.5618	1.7946	15.7254	46.5588	1.5631
Gaussian Filtering [5]	14.1121	97.8730	2.6361	14.2937	90.0193	2.1502
Dilation [5]	10.7398	462.5006	0	10.8099	447.8232	0
Dilation [3]	12.0775	249.7962	0	12.0984	247.3953	0
Erosion [3]	11.7923	284.8480	8.9878	12.0749	250.0867	7.8541
Erosion [5]	10.2542	578.4117	13.3630	10.6196	488.8393	11.5176

Table A.3.5. Parameter values for the set 5-1 and Set 5-2 images after filtering using the different algorithms.

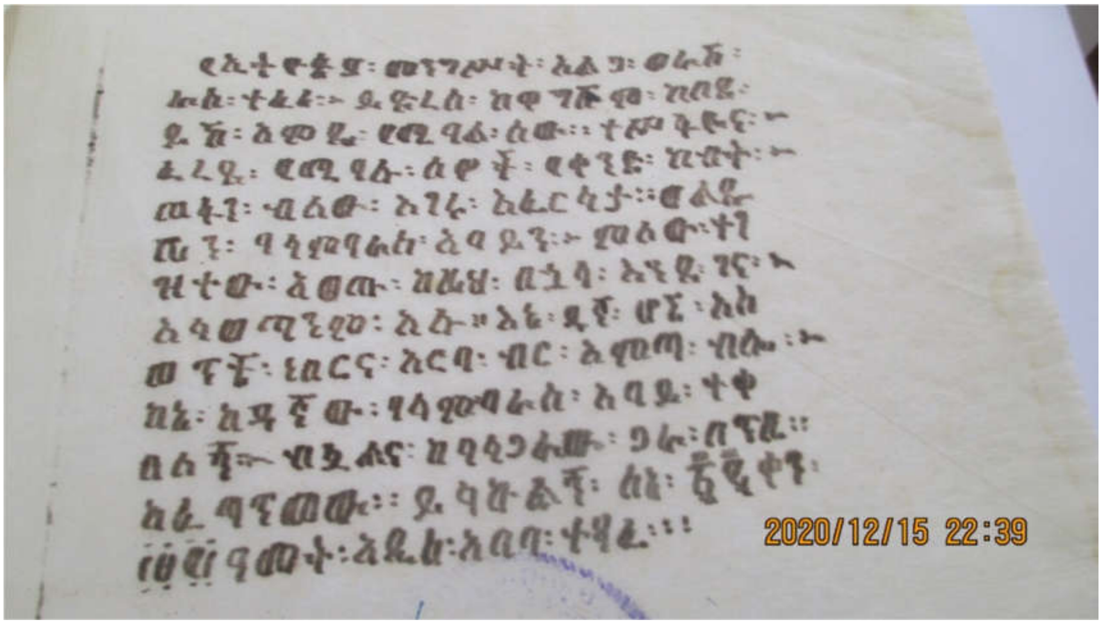
Filtering algorithm	Set 5-1			Set 5-2		
	PSNR	MSE	MAE	PSNR	MSE	MAE
Mean filtering (5 ,5)	17.9653	16.5970	1.0585	16.5863	31.3193	1.2821
Mean filtering [3 ,3)	19.6147	7.7650	0.7446	18.2185	14.7698	0.7871
Median Filtering [3 3]	20.8290	4.4390	0.4834	19.7349	7.3469	0.5686
Median Filtering [5 5]	19.1192	9.7553	0.6511	17.9849	16.4476	0.9474
Gaussian Filtering [3]	16.9754	26.1813	1.3081	15.7632	45.7545	1.5649
Gaussian Filtering [5]	15.4587	52.6433	1.8178	14.4515	83.7124	2.0723
Dilation [5]	12.4834	207.2012	0	11.1463	383.5490	0
Dilation [3]	13.6254	122.4638	0	12.2924	226.2611	0
Erosion [3]	13.0343	160.7735	6.9404	12.1709	239.2732	8.0248
Erosion [5]	11.4662	331.0117	10.3167	10.7423	461.9825	11.7616

Table A3.6. Parameter values for the set 6-1 and Set 6-2 images after filtering using the different algorithms.

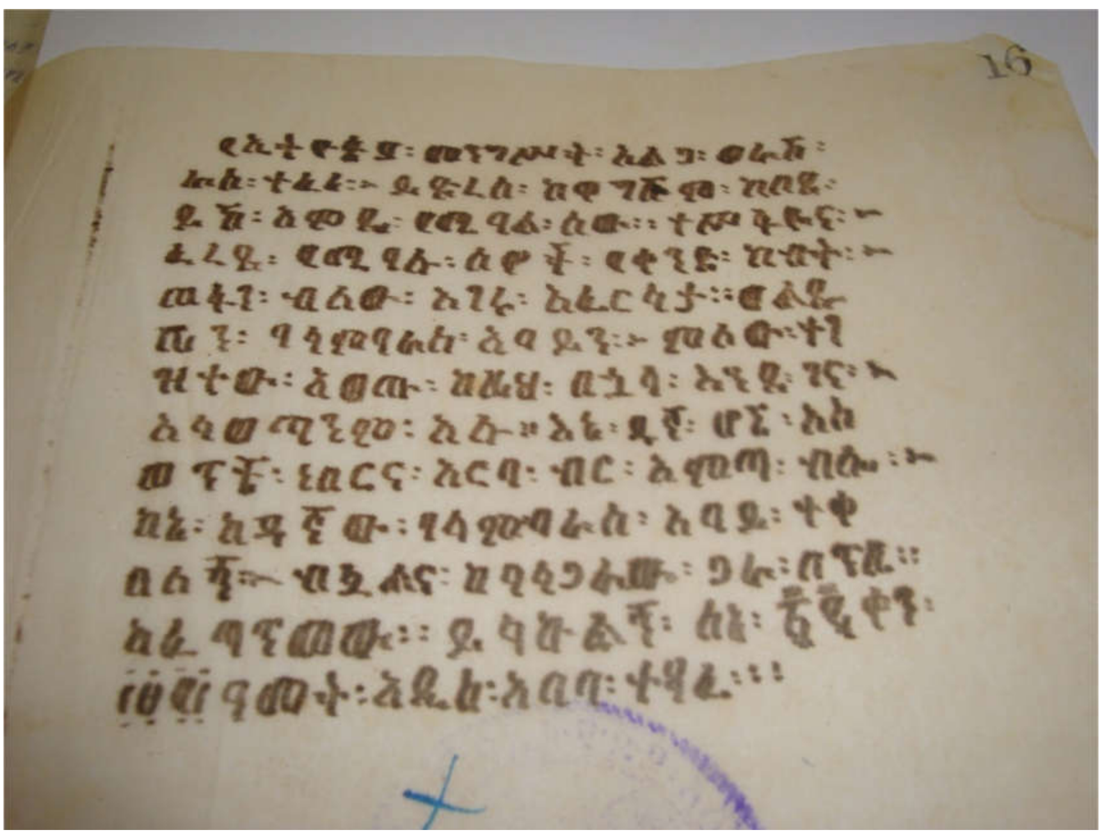
Filtering algorithm	Set 6-1			Set 6-2		
	PSNR	MSE	MAE	PSNR	MSE	MAE
Mean filtering (5 ,5)	16.6266	30.7433	1.3122	16.8172	28.1606	1.1272
Mean filtering (3 ,3)	18.4640	13.1913	0.8771	18.4761	13.1175	0.6689
Median Filtering [3 3]	19.6243	7.7307	0.5290	20.2184	5.8802	0.4408
Median Filtering [5 5]	17.4816	20.7376	0.7422	18.3691	13.7806	0.7652
Gaussian Filtering [3]	15.9769	41.4659	1.5314	15.9189	42.5887	1.4237
Gaussian Filtering [5]	14.8348	70.1655	2.0330	14.6091	77.8518	1.8885
Dilation [5]	12.2467	231.0710	0	11.5997	311.2674	0
Dilation [3]	13.1056	155.5836	0	12.6357	193.1670	0
Erosion [3]	11.9845	260.7182	8.4913	12.3821	217.0968	7.2123
Erosion [5]	10.4483	528.9558	12.8194	10.9219	425.3001	10.7034

Appendix 4. All Images from the denoising operation for the first set of images by all the filtering Algorithms

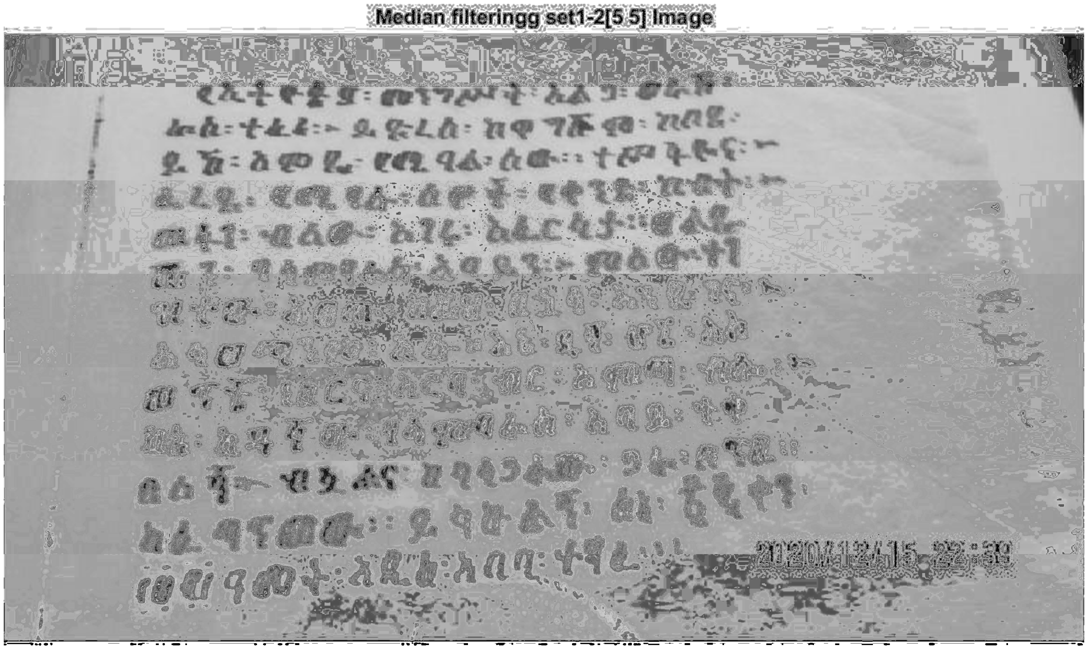
Original image with 8 mega pixel resolution



Original image with 16 megapixel resolution

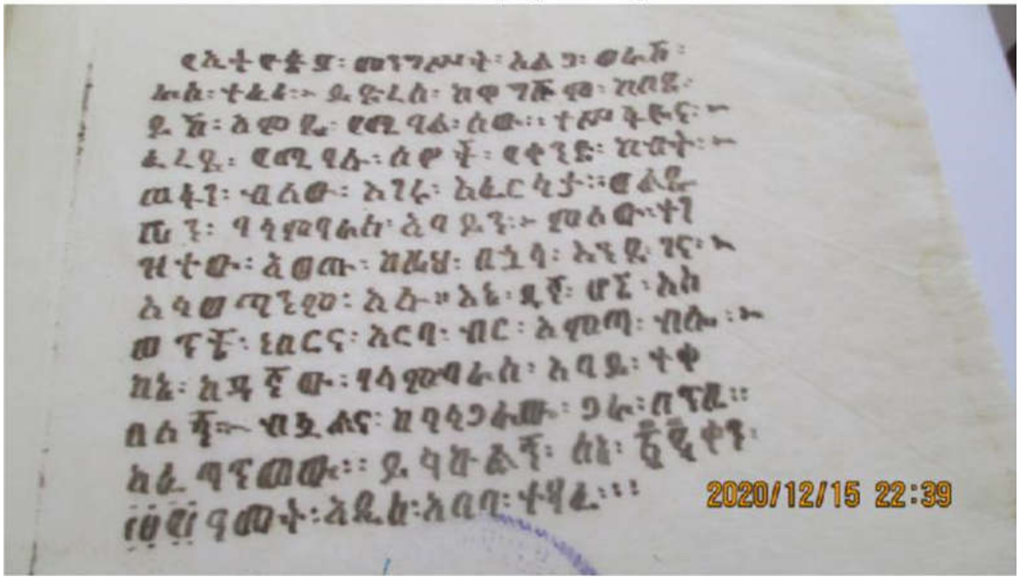


Median filteringg set1-2[5 5] Image

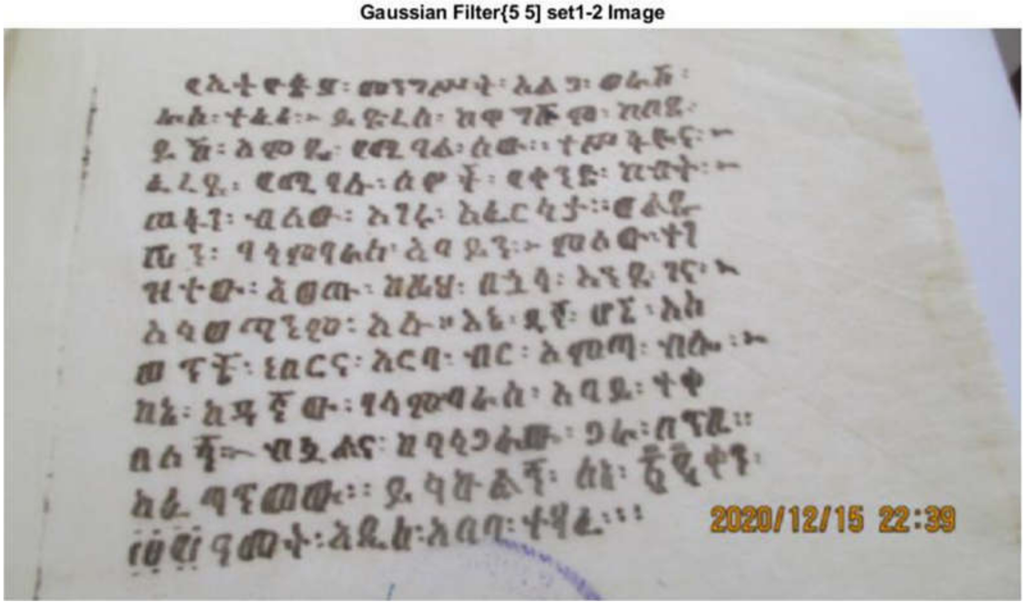


Median filteringg set1-2[3 3] Image

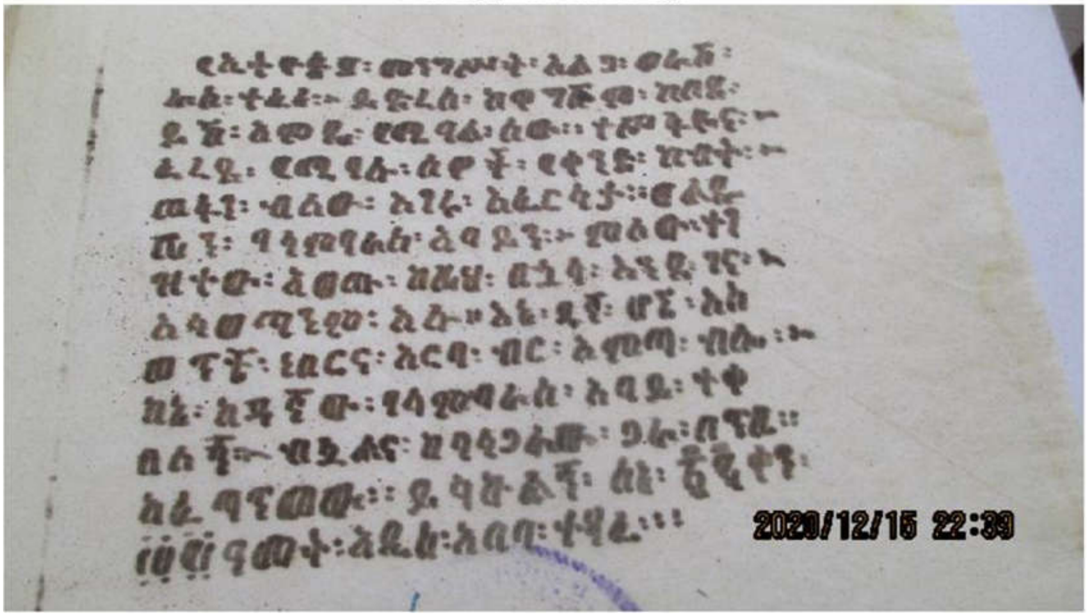
Gaussian Filter[3 3]set1-2 Image



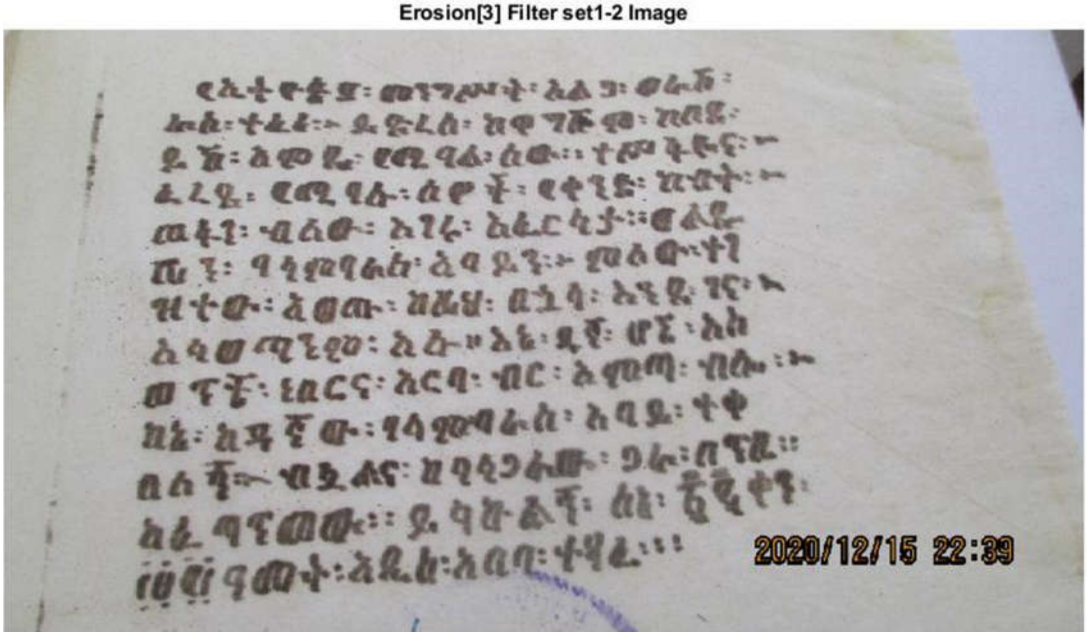
Gaussian Filter{5 5] set1-2 Image



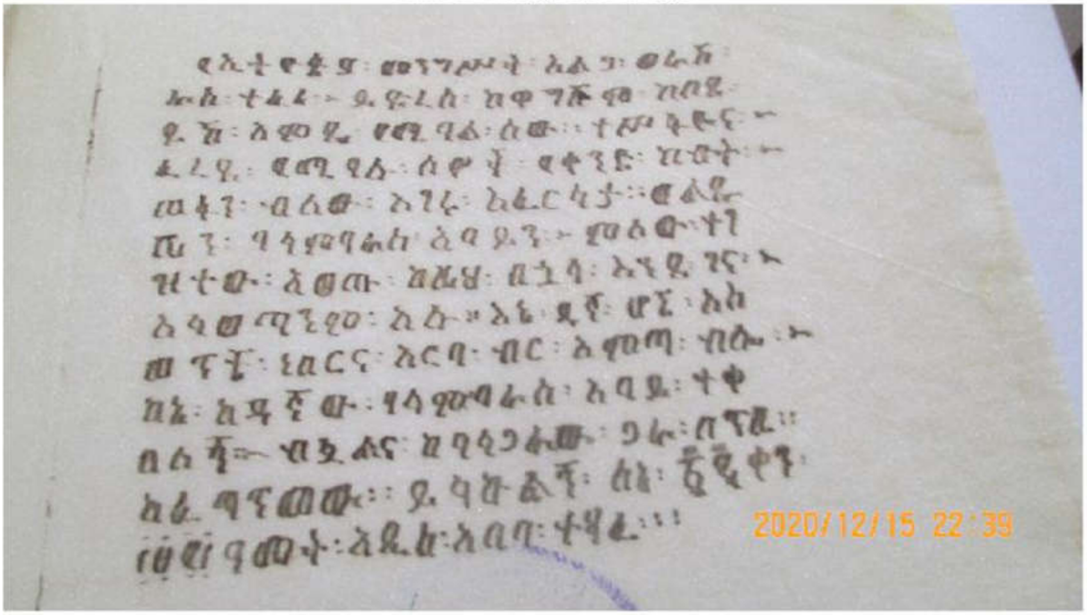
Erosion[5] Filter set1-2 Image



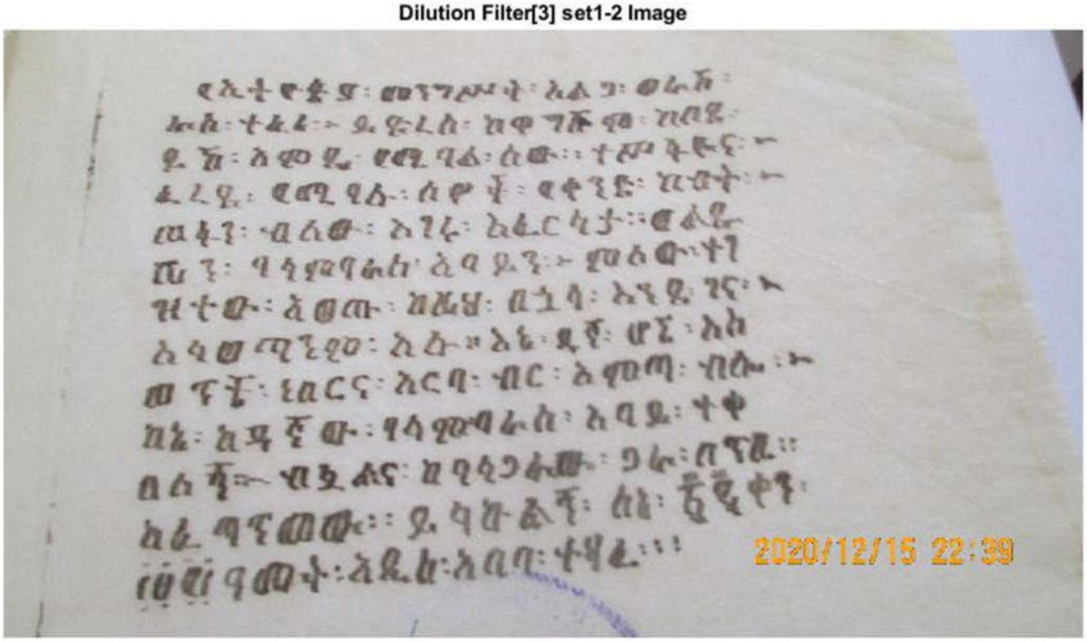
Erosion[3] Filter set1-2 Image



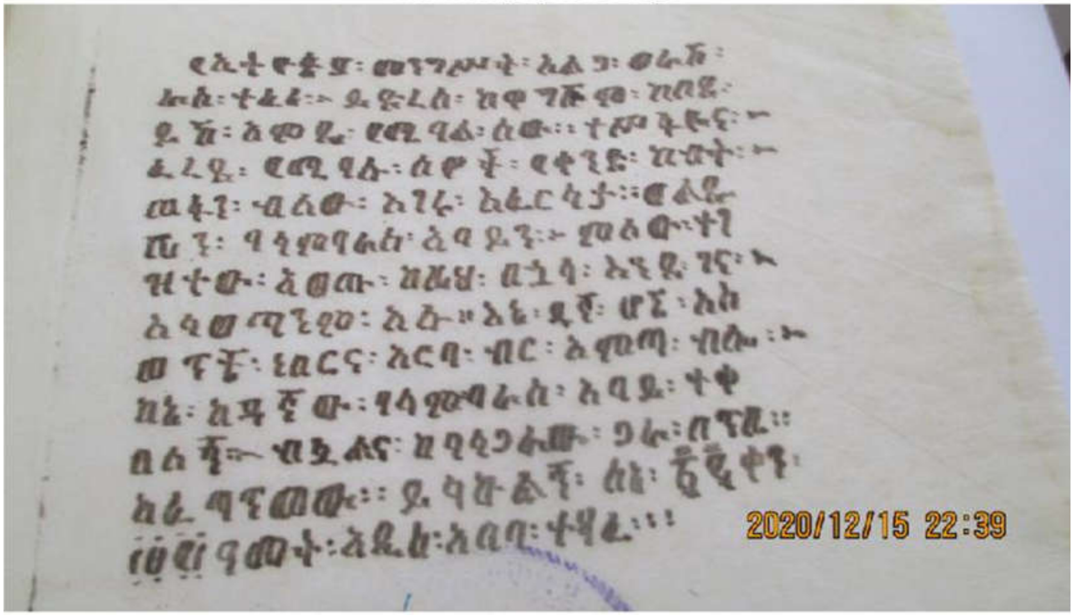
Dilution Filter[5] set1-2 Image



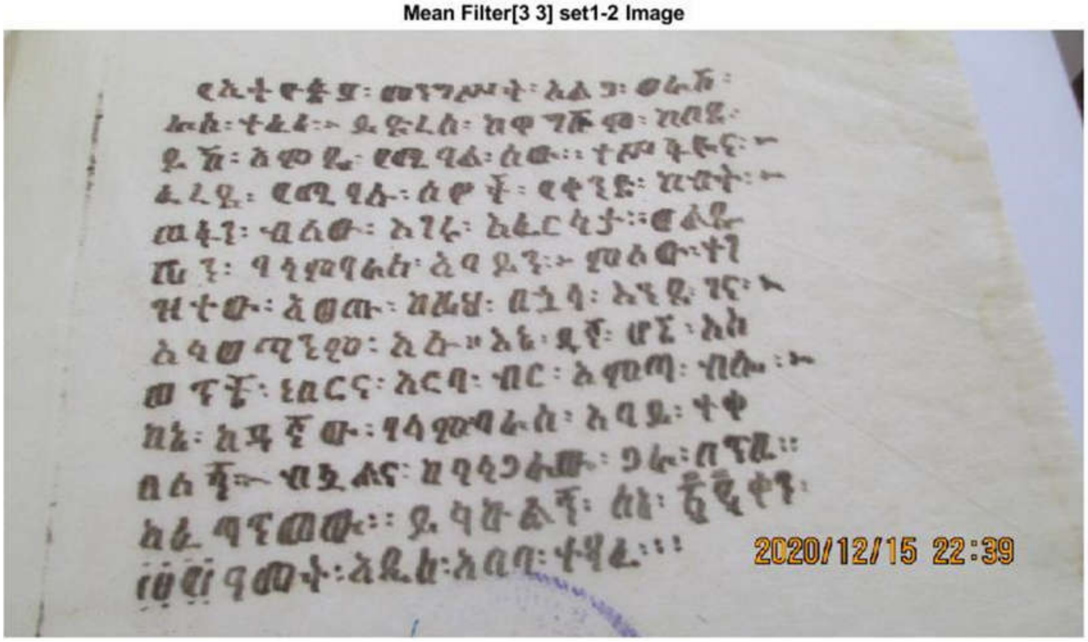
Dilution Filter[3] set1-2 Image



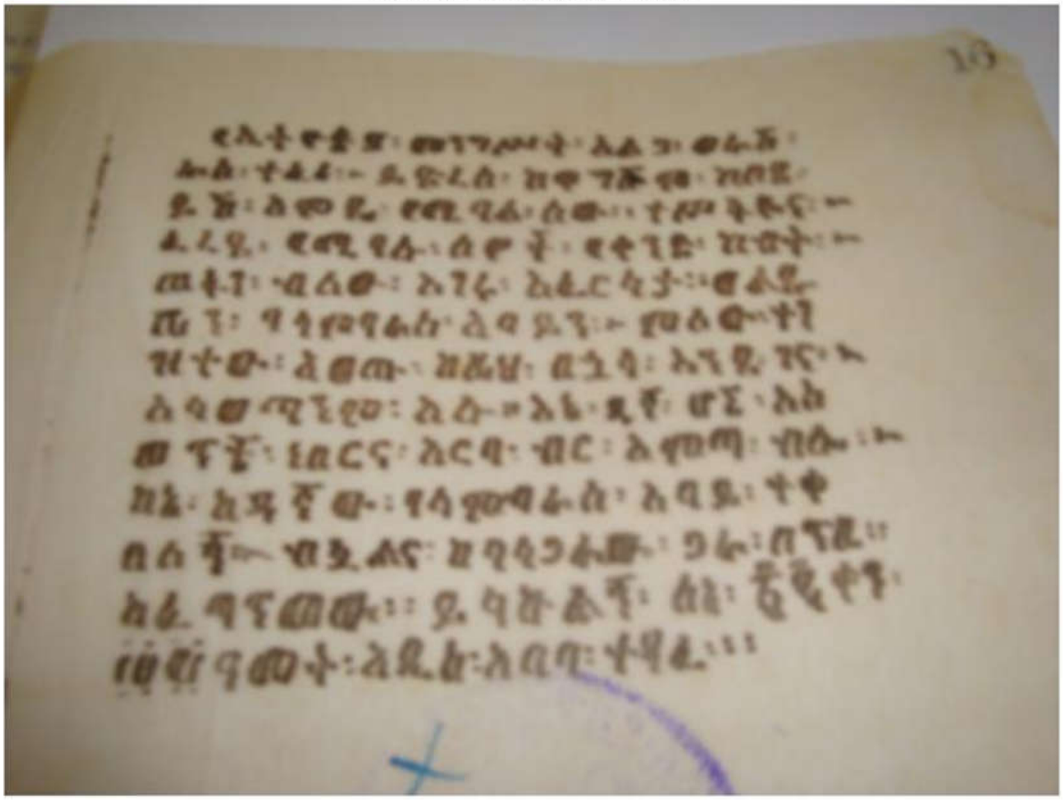
Mean Filter[5 5] set1-2 Image



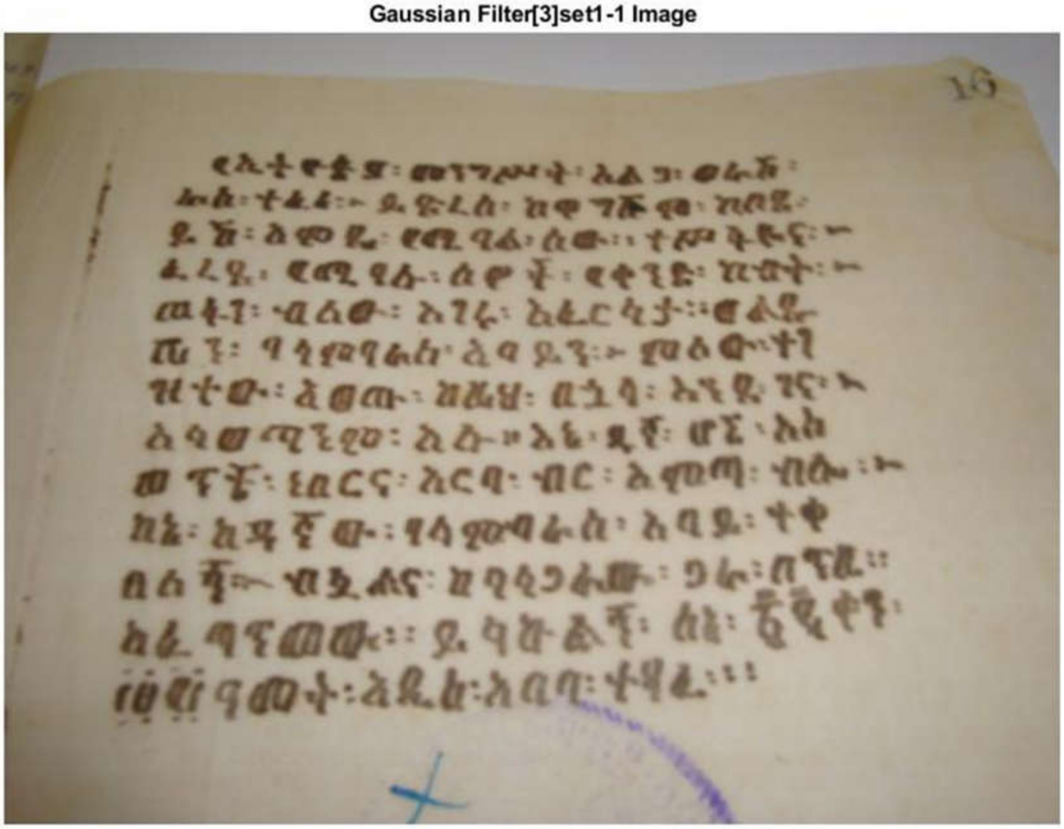
Mean Filter[3 3] set1-2 Image



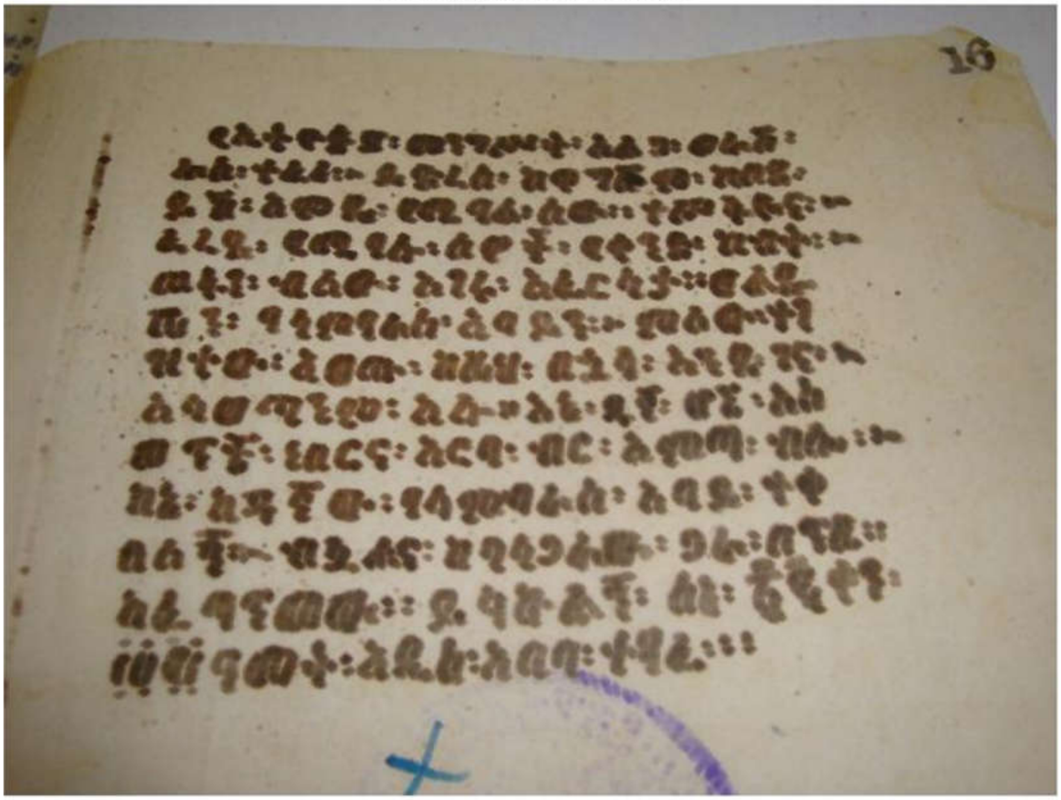
Gaussian Filter[5]set1-1 Image



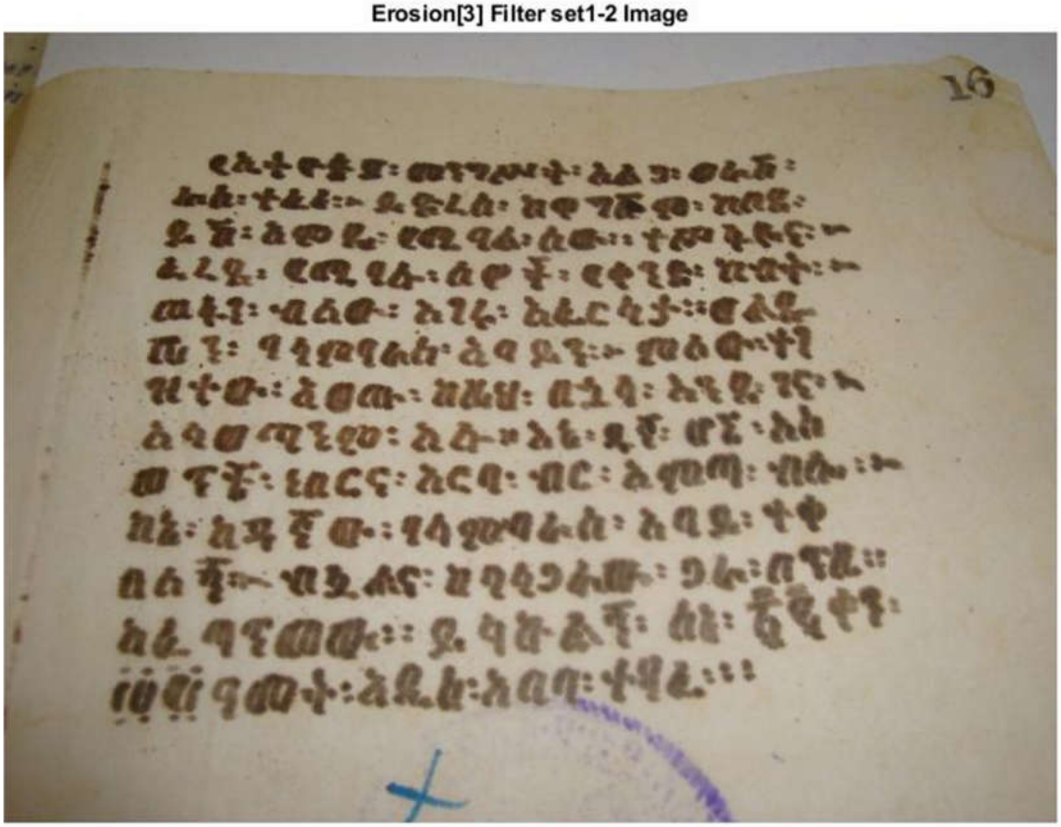
Gaussian Filter[3]set1-1 Image



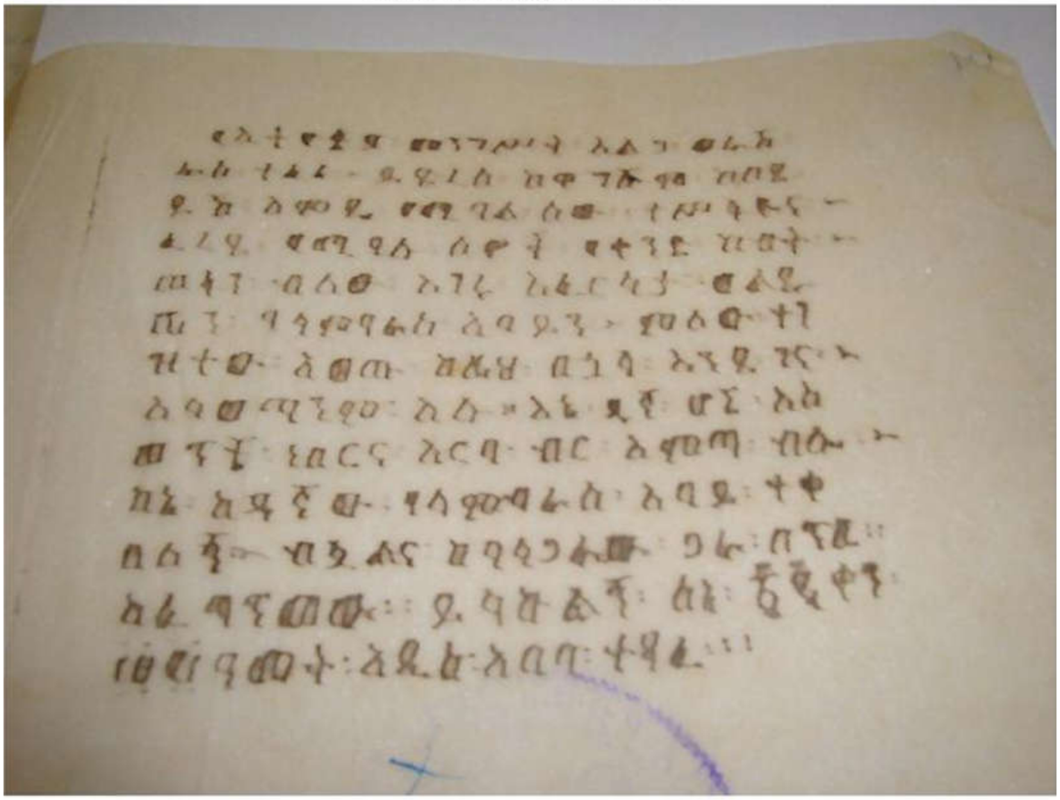
Erosion[5] Filter set1-2 Image



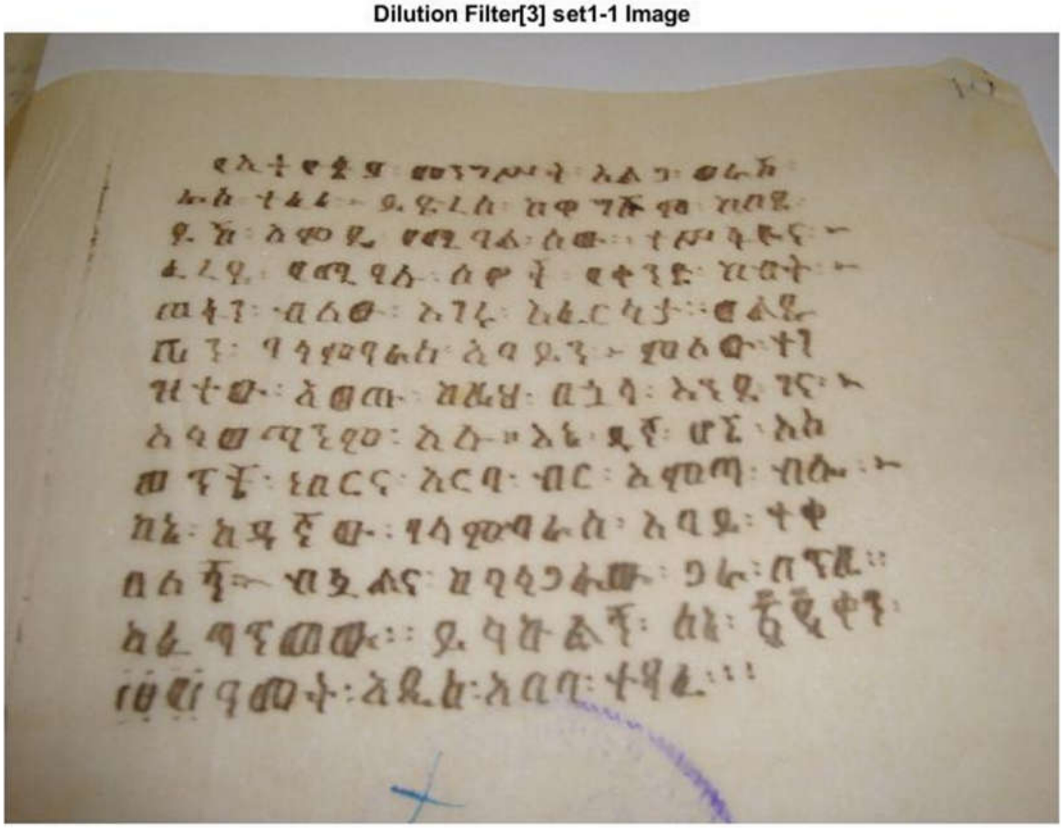
Erosion[3] Filter set1-2 Image



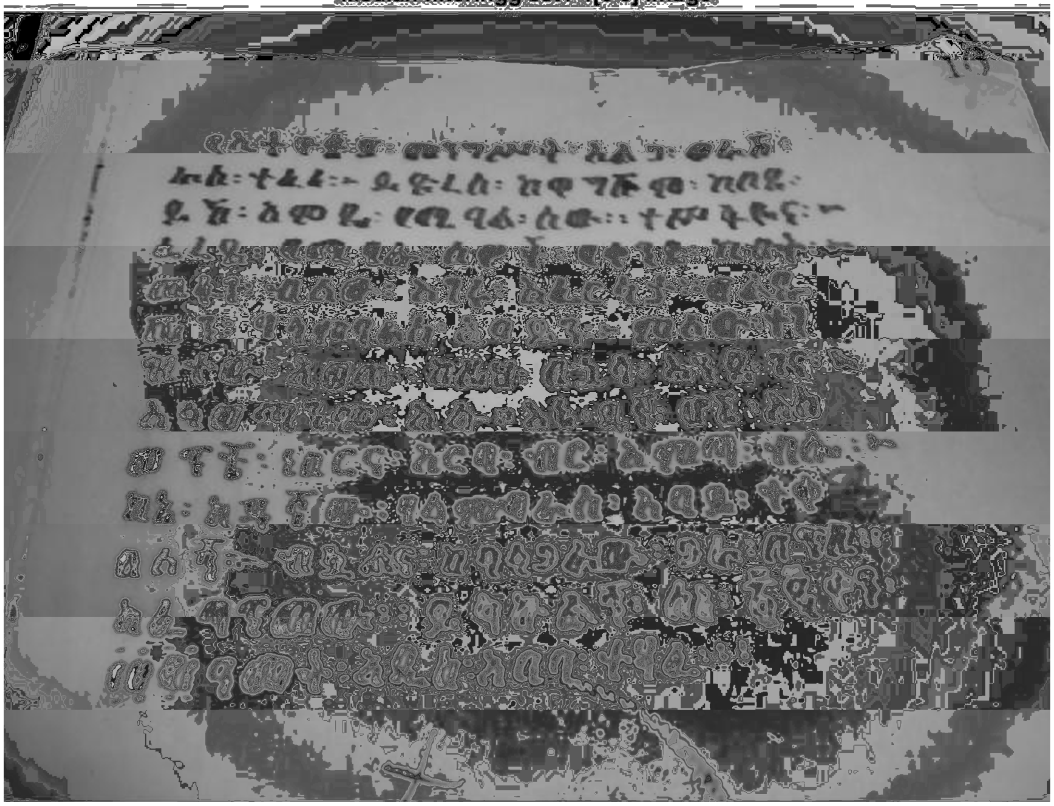
Dilution Filter[5] set1-1 Image



Dilution Filter[3] set1-1 Image

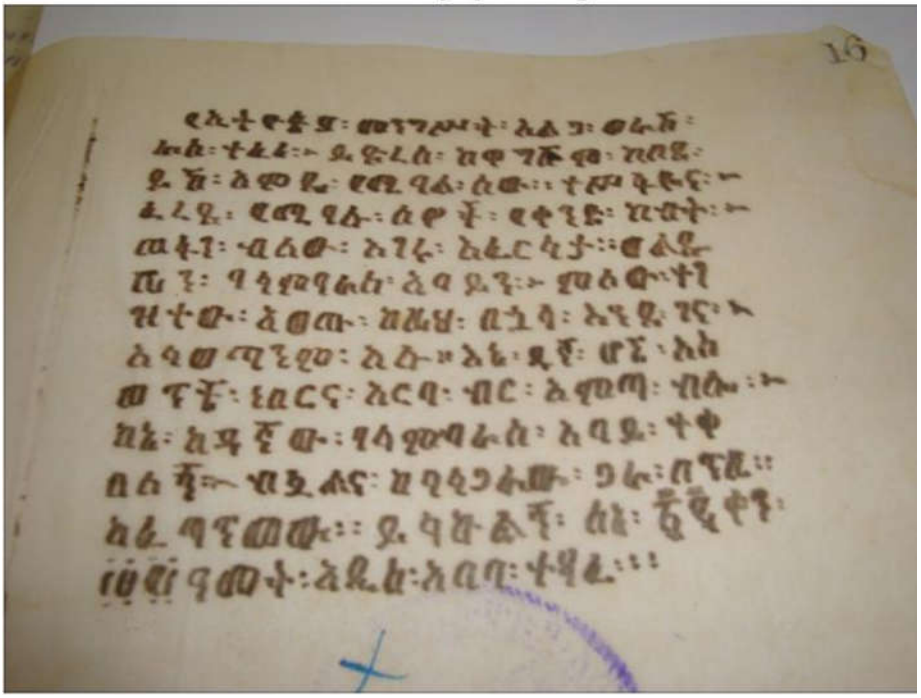


Median filteringg set1-1[5 5] Image

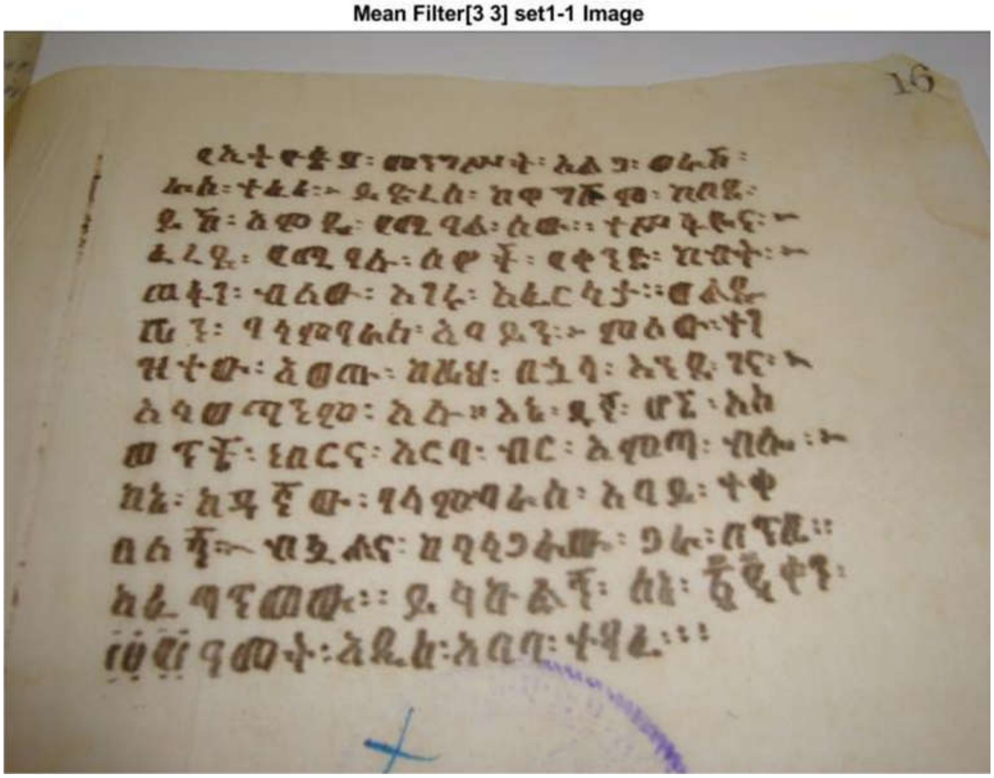


Median filteringg set1-1[3 3] Image

Mean Filter"[5 5] set1-1Image



Mean Filter[3 3] set1-1 Image



Appendix 5. MATLAB Syntax used in the study

Mean Filtering

```
Img=imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');

 m = fspecial('average',5);

 mf=imfilter(Img,m);

 figure,imshow(Img);title('Image')

 figure,imshow(mf),title('Mean Filter Image')

 img = double(Img);

 Pmf = double(mf);

 psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));

 fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);

 Err = immse(Img,mf);

 fprintf('\n The mean-squared error is %0.4f\n', Err);

 mae= sum(abs(Img(:)-mf(:)))/numel(Img);

fprintf('\n The mean-absolute error is %0.4f\n', mae);


 Img=imread ('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');

 m = fspecial('average',3);

 mf=imfilter(Img,m);

 figure,imshow(Img);title(' Image')(

 figure,imshow(mf),title('Mean Filter High Image')

 img = double(Img);
```

```
Pmf = double(mf);
psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));
fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);
Err = immse(Img,mf);
fprintf('\n The mean-squared error is %0.4f\n', Err);
mae= sum(abs(Img(:)-mf(:)))/numel(Img);
fprintf('\n The mean-absolute error is %0.4f\n', mae);
```

Median Filtering

```
Img=imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');
im=rgb2gray(Img);
Md=medfilt2(im,[3 3]);
figure,imshow(Img);title('Image')
figure,imshow(Md),title('Median  Filter Image')
img = double(im);
Pmf = double(Md);
psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));
fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);
Err = immse(Md,im);
fprintf('\n The mean-squared error is %0.4f\n', Err);
mae= sum(abs(im(:)-Md(:)))/numel(im);
fprintf('\n The mean-absolute error is %0.4f\n', mae);
```

```
Img=imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');
im=rgb2gray(Img);
Md=medfilt2(im,[5 5]);
figure,imshow(Img);title(' Image')
figure,imshow(Md),title('Median Filter Image')
img = double(im);
Pmf = double(Md);
psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));
fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);
Err = immse(Md,im);
fprintf('\n The mean-squared error is %0.4f\n', Err);
mae= sum(abs(im(:)-Md(:)))/numel(im);
fprintf('\n The mean-absolute error is %0.4f\n', mae);
```

Gaussian Filtering

```
Img=imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');
Iblur = imgaussfilt(Img,3);
figure,imshow(Img);title(' Image');
figure,imshow(Iblur),title('Gaussian Filter  Image');
img = double(Img);
 Pmf = double(Iblur);
 psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));
 fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);
```

```
Err = immse(Iblur,Img);

fprintf('\n The mean-squared error is %0.4f\n', Err);

mae= sum(abs(Img(:)-Iblur(:)))/numel(Img);

fprintf('\n The mean-absolute error is %0.4f\n', mae);


Img=imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');

Iblur = imgaussfilt(Img,5);

figure,imshow(Img);title(' Image');

figure,imshow(Iblur),title('Gaussian Filter  Image');

img = double(Img);

Pmf = double(Iblur);

psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));

fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);

Err = immse(Iblur,Img);

fprintf('\n The mean-squared error is %0.4f\n', Err);

mae= sum(abs(Img(:)-Iblur(:)))/numel(Img);

fprintf('\n The mean-absolute error is %0.4f\n', mae);
```

Dilation

```
Img =imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1 .jpg');

Md=strel('diamond',5);

Mdf=imdilate(Img,Md);

figure,imshow(Img);title('Image');

figure,imshow(Mdf),title('Dilation  Filter  Image');
```

```
img = double(Img);

Pmf = double(Mdf);

psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));

fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);

Err = immse(Mdf,Img);

fprintf('\n The mean-squared error is %0.4f\n', Err);

mae= sum(abs(Img(:)-Mdf(:)))/numel(Img);

fprintf('\n The mean-absolute error is %0.4f\n', mae);


 Img =imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');

Md=strel('diamond',3);

Mdf=imdilate(Img,Md);

figure,imshow(Img);title(' Image');

figure,imshow(Mdf),title('Dilation  Filter Image');

img = double(Img);

Pmf = double(Mdf);

psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));

fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);

Err = immse(Mdf,Img);

fprintf('\n The mean-squared error is %0.4f\n', Err);

mae= sum(abs(Img(:)-Mdf(:)))/numel(Img);

fprintf('\n The mean-absolute error is %0.4f\n', mae);
```

Erosion

```
Img=imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');
Me=strel('diamond',3);
Mef=imerode(Img,Me);
figure,imshow(Img);title(' Image');
figure,imshow(Mef),title('Erosion Filter Image');
img = double(Img);
Pmf = double(Mef);
psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));
fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);
Err = immse(Mef,Img);
fprintf('\n The mean-squared error is %0.4f\n', Err);
mae= sum(abs(Img(:)-Mef(:)))/numel(Img);
fprintf('\n The mean-absolute error is %0.4f\n', mae);
```

```
Img=imread('C:\Users\etenu\Desktop\good\DSC04086-8pix1.jpg');
Me=strel('diamond',5);
Mef=imerode(Img,Me);
figure,imshow(Img);title('Image');
figure,imshow(Mef),title('Erosion Filter Image');
img = double(Img);
Pmf = double(Mef);
```

```
psnr=10*log10(255/sqrt(mean((Pmf(:) - img(:)).^2)));

fprintf('\n The PSNR value of the Filtered image is %0.4f.',psnr);

Err = immse(Mef,Img);

fprintf('\n The mean-squared error is %0.4f\n', Err);

mae= sum(abs(Img(:)-Mef(:)))/numel(Img);

fprintf('\n The mean-absolute error is %0.4f\n', mae);
```