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Soil

Characterization

Using Digital

Image Processing

January 2000

Soil Characterization Using Digital Image Processing.

By

Kshitija S. Naphade

A Thesis

Presented to the Graduate and Research Committee

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Kshitija S. Naphade

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Abstract.

The use of computers in many engineering fields is widely accepted. The field of geotechnical engineering is not far behind. The use of computers not only automates the process of soil characterization, but also makes it more objective. The chances of human error are minimized, thus saving a lot of energy, time and most importantly, money.

This thesis deals with the measurement of the size distribution of coarse-grained soils. It concentrates on a portion of the spectrum of sized encountered in soils. The aim of the thesis is to measure the size of soil particles using image processing techniques. The thesis discusses the hardware used for the characterization process and explores various software packages for the image analysis.

However, due to several problems with the framegrabber and its compatibility with Red Hat Linux 6.0, the testing procedure outlined in Chapter 2 of the thesis could not be carried out. The background work for the testing being complete and the soil samples being ready, the testing would be easy to carry out for anyone planning to work further on this topic.

Chapter 1: Introduction.

Determining the properties of soil to estimate its strength is one of the primary goals of geotechnical engineering. However, geotechnical engineering is based largely on empirical relations. The data obtained from various tests is highly subjective, which further complicates the existing variability in soil conditions over space and time.

Various test methods exist to characterize and classify soil, and one of the most preliminary methods is to determine the grain size distribution of soil. Grain size distribution characterizes soil based on the premise that soils with similar shape and size distribution have similar properties. The traditional method for determining grain size distribution involves sieve analysis (coarse-grained soils) and hydrometer analysis (fine grained soils). A typical grain size distribution curve obtained from sieve analysis is shown in Figure 1.1.

Sieve analysis involves passing the soil through a set of standard sieves. The weight of soil retained on each set of sieves is measured as percent finer by weight and is plotted against the particle size. There are several limitations to this method, which are outlined below. Soil properties depend not only on the grain size distribution of particles, but also on various other factors like mineral constituents, structural arrangements, geological history, etc. The sieves also require maintenance. On repeated use, the sieve openings get distorted and give erroneous results. More importantly, sieve analysis doesn't necessarily measure the particle diameter in the conventional

sense. Soil particles are three-dimensional and particle size based on sieving captures the intermediate dimension. (Murthy, 1993).

In case of fine-grained soil, sieve analysis is not appropriate. The physical properties of clay such as plasticity control the mechanical behavior rather than particle size distribution.

Sieve analysis cannot be performed on fine-grained soil. So the alternative to it is hydrometer analysis. Hydrometer analysis is based on the principle of sedimentation and Stoke's law. The grain size is calculated from the distance of sedimentation of soil particles in a hydrometer filled with soil-water suspension. The limitations to hydrometer analysis are described here. It assumes that all soil particles are spherical. However, clay and silt particles are plate-like and flaky. Soils contain particles having different minerals and thus the specific gravity cannot be characterized using an average value, as is done in this test. The test assumes that the soil particles are separated from one another. Although a dispersing agent is added to the soil-water suspension to ensure the validity of this assumption, some particles flocculate and settle more rapidly than individual particles. The test also assumes that the particles do not interact with one another. But this may not be necessarily true if the concentration of the soil-water suspension is high.

The main advantages to these traditional methods are that they are inexpensive and easy to perform. With the advance of technology and the use of computers, automation is gaining a lot of importance. It not only expedites the process, but also produces more objective results. This thesis aims at introducing automation procedures for determining grain size distribution of soil using image-processing techniques.

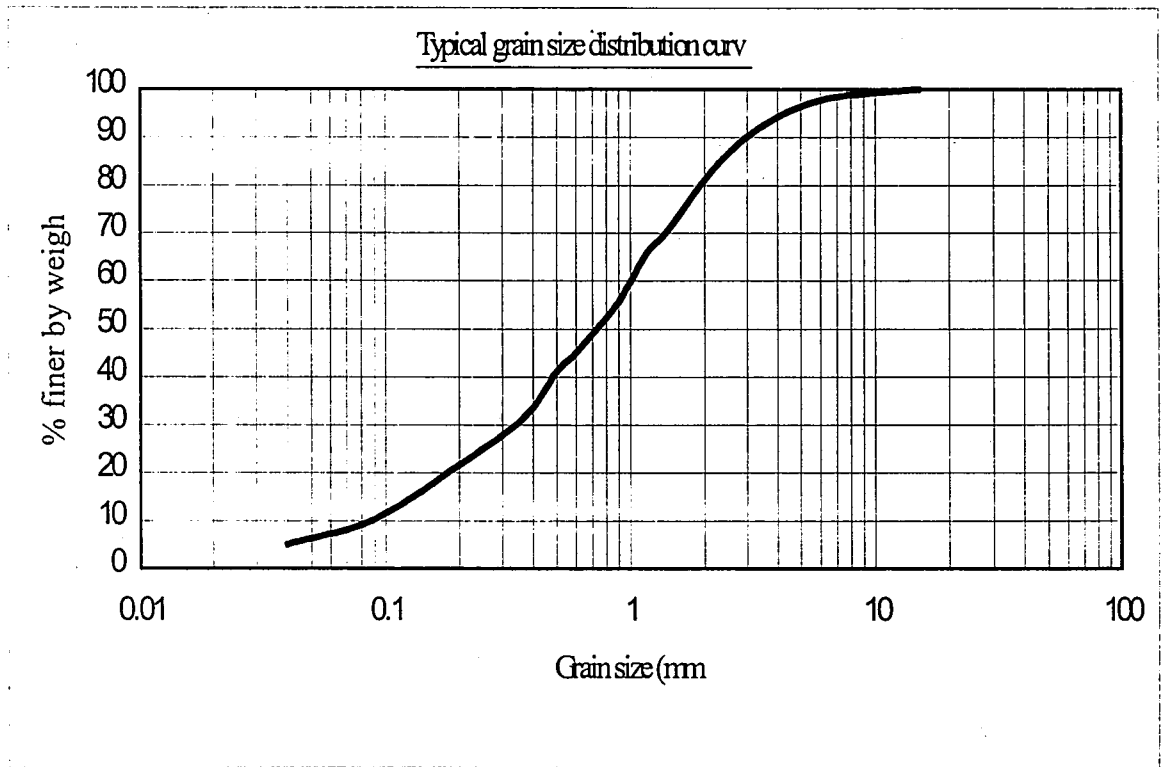


Figure 1: Typical grain size distribution curve.

Chapter 2: Literature Review.

2.1 Introduction

The field of Digital Image Processing (DIP) is continuously evolving and is finding many applications in several fields. Soil characterization is an important aspect of geotechnical engineering which has been given a great amount of attention since the past few years. Upon studying the use of image-processing techniques in various fields, it can be deduced that there is an application in geotechnical engineering as well. (Macedo et. al. 1999 and Moore et. al. 1993).

Image processing, has found applications in various fields from criminology to factory automation. Some of the fields are briefly described here.

DIP is used in *Criminology* for fingerprint matching. The shape (orientation and direction of ridges) and size (ridge thickness) can be characterized efficiently. (Mardia et. al. 1997).

Medical Science uses DIP for various purposes. Some of them include tumor detection, bone, tissue and cell analysis (classification, and counting of cell structures), DNA typing (analysis, classification and matching of DNA material), Angiography (enhancing blood vessel imagery by subtracting a baseline X-ray image from another image with ray-opaque liquid in the bloodstream), characterization of dust for effects on humans (coal dust, silica dust, flyash, diesel soot, etc.) and many more.

Target acquisition and guidance (recognizing and tracking targets in real-time for smart bomb and missile guidance systems) has become more precise since the use of DIP methods in *Defense and Intelligence* departments.

Various sciences and engineering departments use DIP extensively. For example, *Material Science* researchers use it for automatic counting and classification of objects like impurities, characterizing fine particle systems using fractals (*Powder Metallurgy*), etc.

DIP techniques in *Factory Automation* have not only made manufacturing very efficient but also cost effective by saving time. It is used to analyze features of manufactured parts on an assembly line to look for defects, classify various manufactured parts, etc.

Remote Sensing uses DIP extensively. It is used for landcover analysis (measuring geometric features), fractal surface reconstruction for modeling natural terrain, automatic finding of main roads in aerial images using geometric-stochastic models and estimation, and to the study of morphology of cities, etc.

Various other fields are now finding applications of image processing. Some of them are *Cartography*, crack propagation studies in *Mining Industry*, hydro-metallurgical technology (distribution and connectivity of pore spaces for retrieving ores by leaching), *Eriometry* (characterization of fine-particles using diffraction pattern generated by laser beams), *Granulometry* (determining size distribution of particles in an image), *Environmental Engineering* (study of dispersion of smoke plumes), etc. (Gonzales and Woods 1992, Jahne 1991, Kaye 1989 and Russ 1994). Two applications, somewhat analogous to the problem at hand are discussed below.

2.2 Applications in Medical Science

Image processing has become an integral part of medical science. Some of the applications are discussed. Radiology traditionally involves the use of X-rays in the diagnosis of disease. In recent years, radiology also includes diagnosis by a method of organ scanning, using radioactive isotopes. Tomography is a radiological technique for obtaining X-rays of internal organs, by focussing on a specific plane within the body. Organs that are overlaid by other organs or tissues cannot be seen on a conventional X-ray. Tomography is the solution to this problem.

Digital Subtraction Angiography (DSA) or simply angiography is an electronic technique used for imaging blood vessels. An X-ray-opaque liquid is inserted into an artery or vein. The image is captured and the computer subtracts this image from a previous image without the X-ray-opaque liquid. The images of the soft tissues and bones are the same and are eliminated in the subtraction. The blood vessels containing the X-ray- opaque liquid are thus highlighted.

MRI relies on the response of magnetic fields to radio-frequency waves. This produces computer images that provide structural and biological information about the tissue. Computerized axial tomography (CAT scanning) is the computer enhancement of tomography. This method measures the attenuation of X-rays entering the body from many different angles. From these measurements, a computer reconstructs the organ under study in a series of cross sections or planes. The technique allows soft tissues to be clearly differentiated in the images reconstructed by the computer. These procedures add enormously to the diagnostic information that can be provided by

conventional X-rays. They essentially provide 2-D images of cross-sections of the body. With the advances in computer technology, it is now possible to construct 3-D views from the digital data available from the scanners. These holograms are useful planning surgical details.

DNA fragment length can be measured using image-processing techniques. An image is acquired using an atomic force microscope. These methods reduce operator-interaction and thus make the results more objective.

A lot of research is focussed on the use of image processing in medical science in the past decade. New methods using concepts of fractals, neural networks, wavelets, etc. are being introduced for better imaging and enhancing the quality of images. The advances in computer technology have further helped in advancing this research.

An important step of 3-D imaging in medical science is registration. Registration techniques quantitatively relate information from one image to another. This is essential for developing a 3-D view from 2-D images. Registration also helps superimposing images from one study over those of another study. Experiments are being conducted to measure the errors in registration and to minimize these errors.

Endoscopy is the medical examination of the interior of the body, usually through a natural body opening, by the insertion of a lighted optical shaft or open tube. A method of estimating the surface shape from the endoscopic image sequence is being developed. In the first stage, camera movements are estimated and surface shape is roughly estimated. In the second stage, the surface shape is refined using a weighted multi-view method.

A new algorithm is being developed for shape-based interpolation of CT and MRI images (as opposed to linear interpolation, which only relies on pixel position). The shape-based interpolation demonstrates a significantly smoother representation of the anatomy than images processed by linear interpolation. Research for improving the operations of segmentation of 2-D and 3-D images and edge detection using neural networks and deformable models is currently on.

2.3 Applications in Pore Characterization:

Porosity is an important property of not only soils but also other materials like carbon, cement, membranes, wood, ceramics, etc.

The use of computed tomography (CT) in medical science inspired scientists to use CT in soil science to characterize porosity for determining transport processes in soils. This testing acquires soil images and measures the pore size and distribution using image processing methods.

The microstructure of pores of activated carbon fibers (ACF) has been studied using transmission electron microscope (TEM). The images obtained from the TEM are input into the computer and analyzed using the fast Fourier transform (FFT). Fourier transforms carry out frequency analysis to determine the pore size distribution. The results from these studies have been compared to those from other tests and have been found satisfactory. (Anselmetti et. al. and Endo et. al.)

It is well established now that the porosity of cement paste has a direct effect on properties like strength, permeability, toughness, durability, etc. Mercury intrusion

porosimetry (MIP) has been the most common method to characterize the pore structure. Several limitations posed by MIP necessitated the development of other techniques. Wood's metal is substituted for mercury as the intruding liquid. Using a scanning electron microscope and imaging techniques, the changes in the sample during intrusion can be observed and the pore structure thus quantified. (Willis, et. al. 1998).

Image processing has also been used in grain counting for the analysis of precipitates in aluminum. The algorithms used determine the number of grains in a specified area, the mean grain diameter and the standard deviation. This data is useful in determining the fraction of the surface of aluminum covered by precipitates.

The pore size distribution in fabrics has also been studied using image processing. This is analogous to determining the apparent opening size (AOS) in geosynthetics. Three different definitions of "pore size" have been used to determine the distribution and they correlate well with data from traditional tests.

Soil porosity has been studied not from a geotechnical point of view, but for applications in agriculture and petroleum geology. Quantifying pore sizes and pore size distribution is necessary in agricultural practices to accurately determine rates of water flow, solute (fertilizer) transport, etc. Traditional methods use intrusion techniques to determine the porosity. With the advances in technology, these methods have been modified and now incorporate imaging techniques. Paraffin, containing a fluorescent dye is impregnated into the soil sample. Images are acquired and digitized and image processing used to measure the area and perimeter of each pore.

Petroleum geologists consider pore spaces in sedimentary rocks as a crucial factor since its applications range from hydrocarbon reservoir characterization to hydrologic and environmental issues. The samples are digitized using an optical microscope (OM) and an environmental scanning electron microscope (ESEM) to obtain images at several magnifications. The image processing techniques measure the pore area and perimeter and calculate the pore size distribution.

Characterizing soil particles is very similar to characterizing pores in a substance. The particles, like the pores, need to be identified, their area measured and the mean diameter calculated. However, in case of soil particles, overlapping creates problems. Two small pores if touching one another, constitute a single pore but two soil particles touching one another do not make one particle.

2.4 Problem Statement

This research aims at using DIP to characterize soil particles. Its goal is to measure the size of soil particles and determine the grain size distribution of the sample. Images of soil samples will be acquired using a charged coupled device (CCD) camera and fed into the computer. These images will then be analyzed to measure the required parameters.

Initially, two uniformly graded samples with different mean grain size would be tested. Later, a well graded soil sample will be tested. The well graded soil sample will be analyzed at different magnification levels to account for the wide array of particle sizes. The results will be compared to the grain size distribution of the sample

determined using sieve analysis. The results and conclusions are described in Chapter 6 while the future scope of this work is detailed in Chapter 7.

Chapter 3: Hardware Review.

3.1 Introduction

The first step in analyzing the soil samples using image processing, is to review the instruments (hardware in general) needed for the process. Each component of the entire system is discussed in this chapter. Figure 3.1 shows the schematic diagram of the system.

3.2 Components

The main components of the system are a Light source, a CCD Camera, a Video monitor, a workstation, a PC, and an SGI workstation.

Light Source: The light source is a 150-Watt Fiber Optic Illuminator from BDS Technologies, Inc. It illuminates the soil sample with a ring light, to facilitate the camera to grab the image. It illuminates the object uniformly, minimizing glare and shadowing.

Charged Couple Device (CCD) camera: This is a TenX Zoom camera manufactured by Navitar. It has a 0.5X and 2X adapter with 0.25X lens or 2X lens either of which could be attached in any permutation to get the required magnification. The CCD camera is used to capture the soil image, which is displayed on the video monitor.

Video Monitor: The video monitor is a 20-inch monitor manufactured by Sony, model HR Triniton.

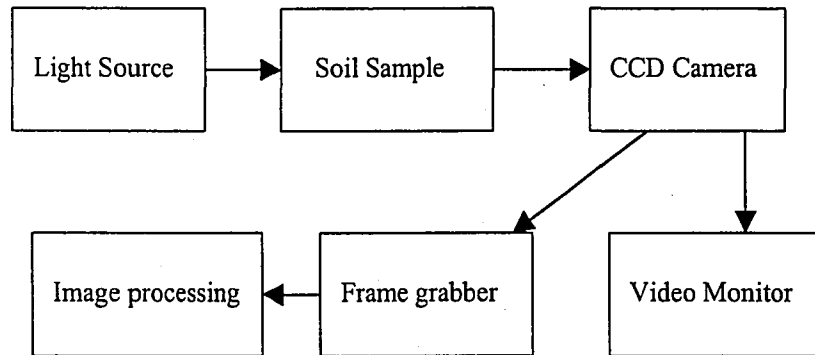


Figure 3.1 Schematic for the Image acquisition process.

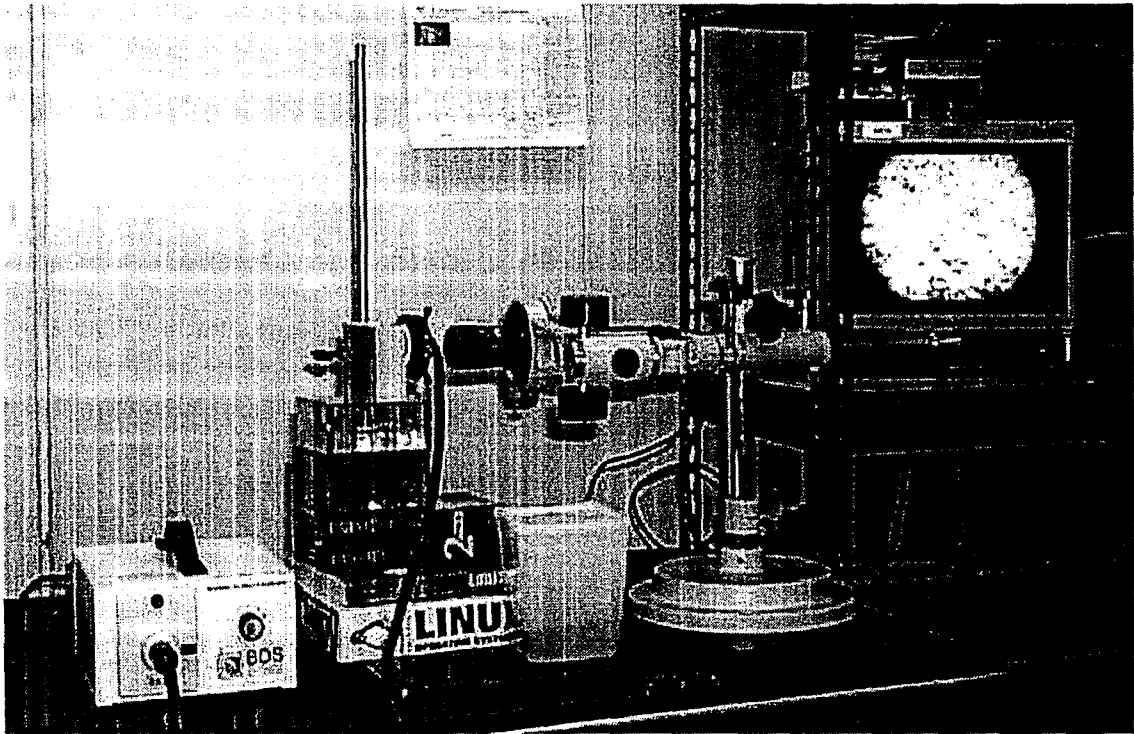


Figure 3.2 Digital Image of the Image Acquisition System Components

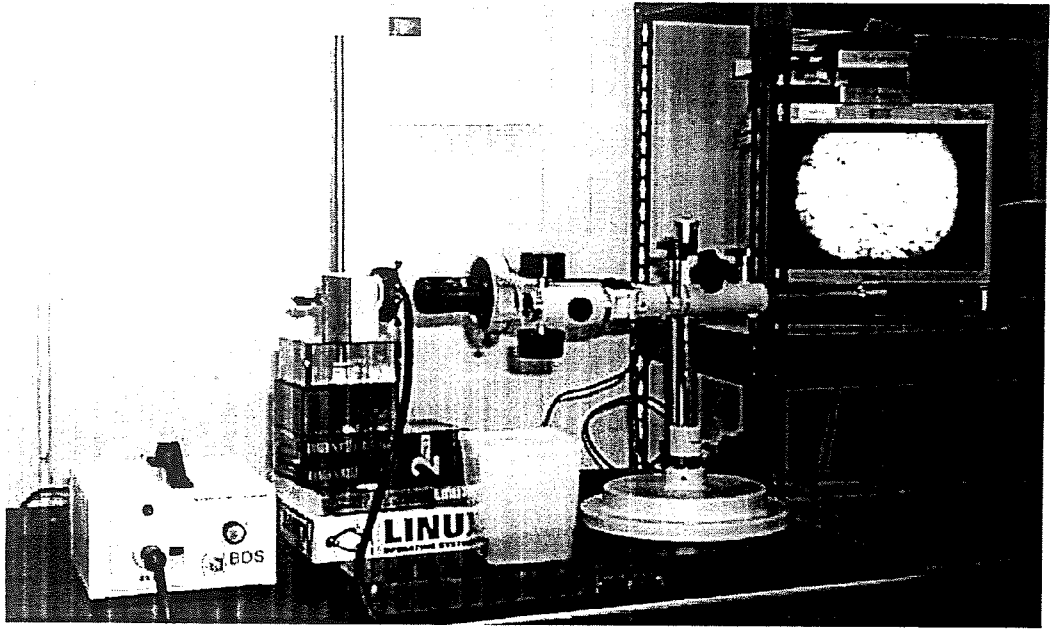


Figure 3.2 Digital Image of the Image Acquisition System Components

Workstation: The workstation, running on Red Hat Linux 6.0, has a framegrabber, which converts the analog image from the video monitor to a digital image.

PC: The PC is a Pentium 300 MHz, works under Windows 98 and has a 64 MB RAM with a 10GB hard disk. It is used for processing the images acquired using the CCD camera and digitized by the framegrabber.

SGI Workstation: This Octane machine, running on Unix is connected to the Lehigh Network. It runs at 175 MHz and has a 4GB SCSI disk drive with 256-MB RAM and 20 inch color monitor. This is also primarily used to operate the image processing software that run on Unix machines, (e.g. Matlab).

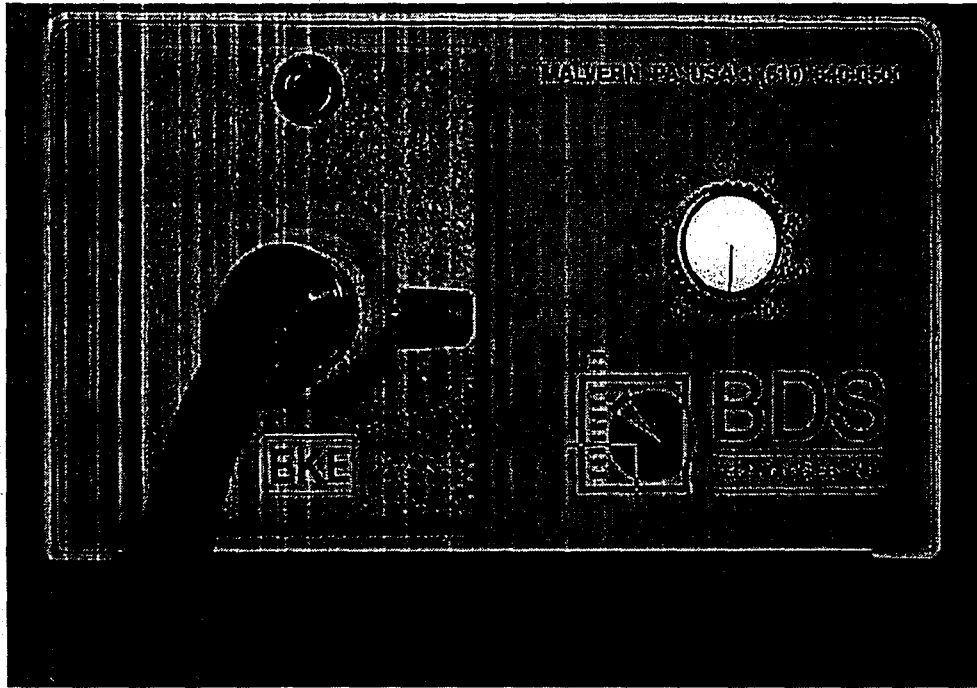


Figure 3.3 Fiber Optic Illuminator

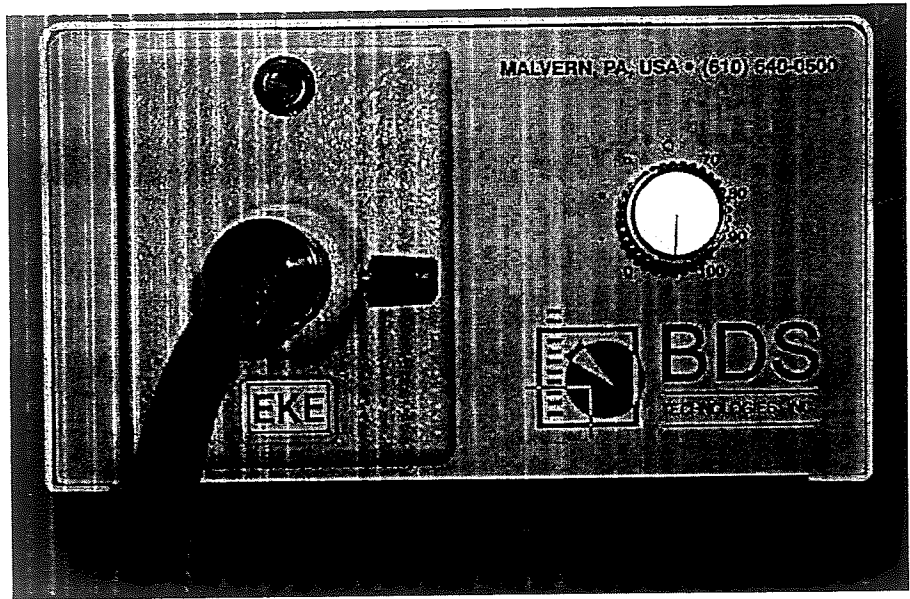


Figure 3.3 Fiber Optic Illuminator

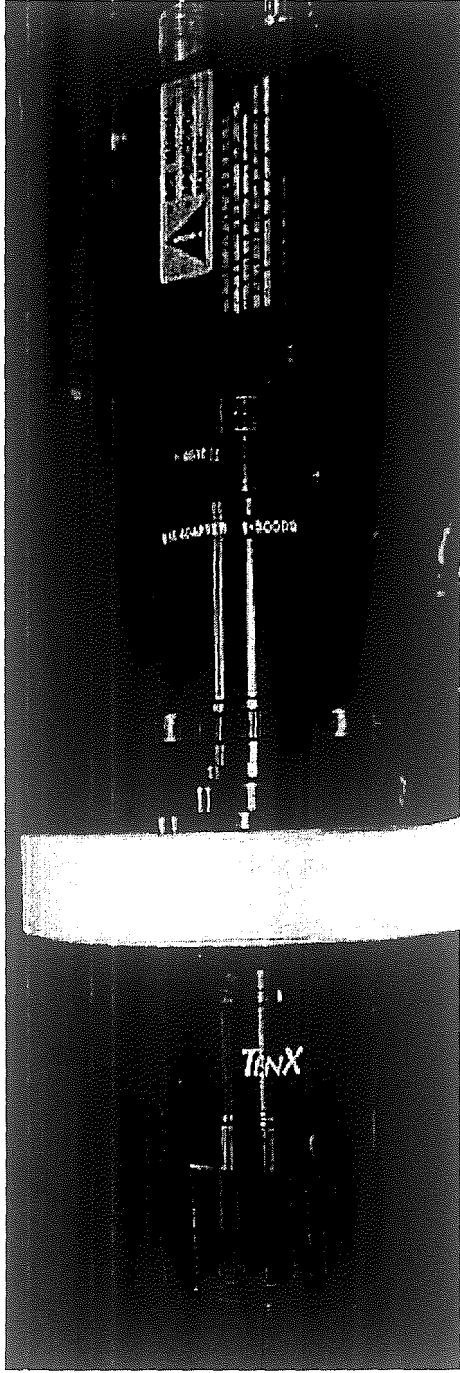


Figure 3.4. Charged Couple Device (CCD) Camera

INTENTIONAL SECOND EXPOSURE

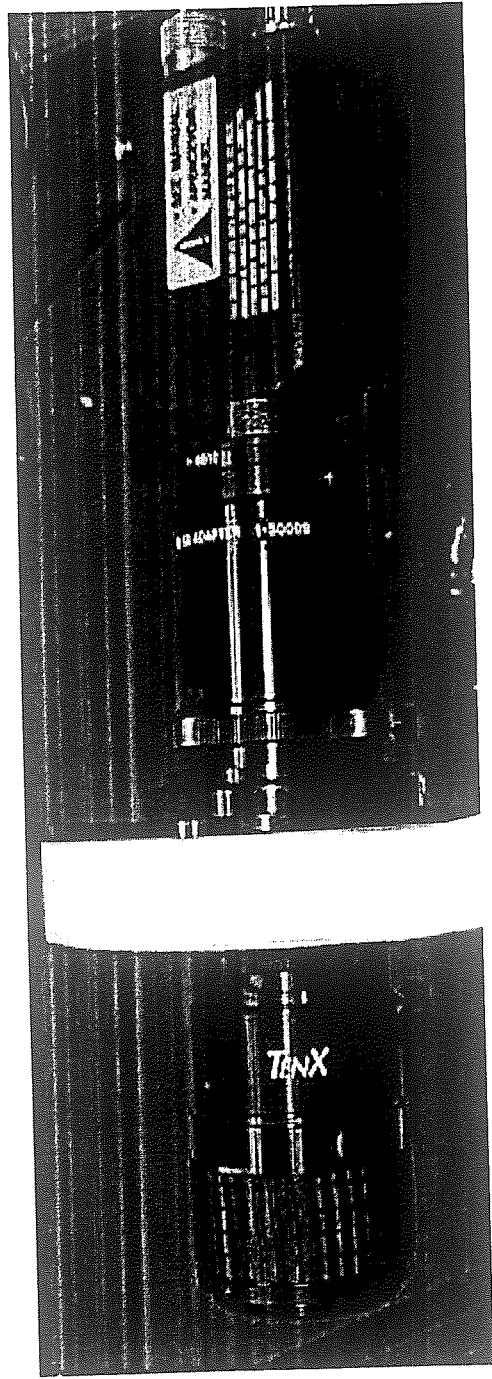


Figure 3.4. Charged Couple Device (CCD) Camera

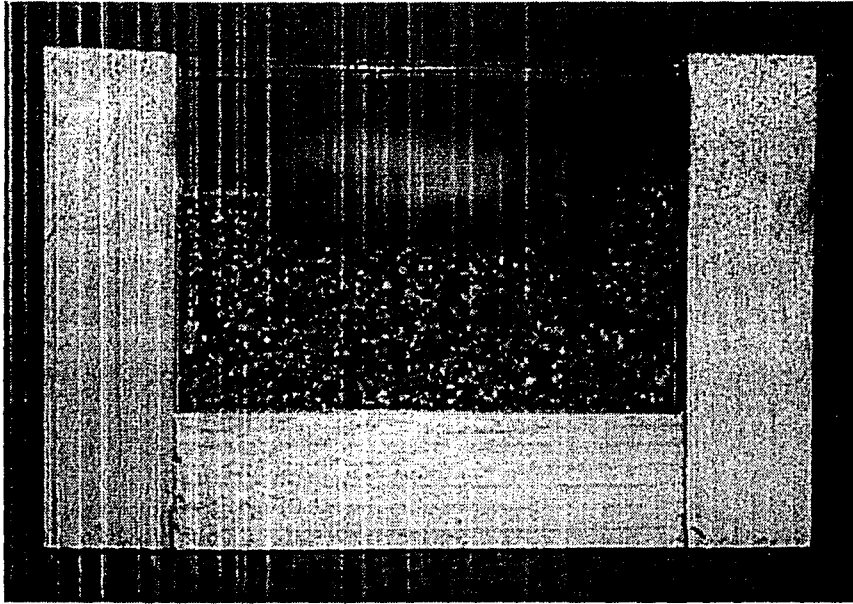


Figure 3.5 Soil Sample

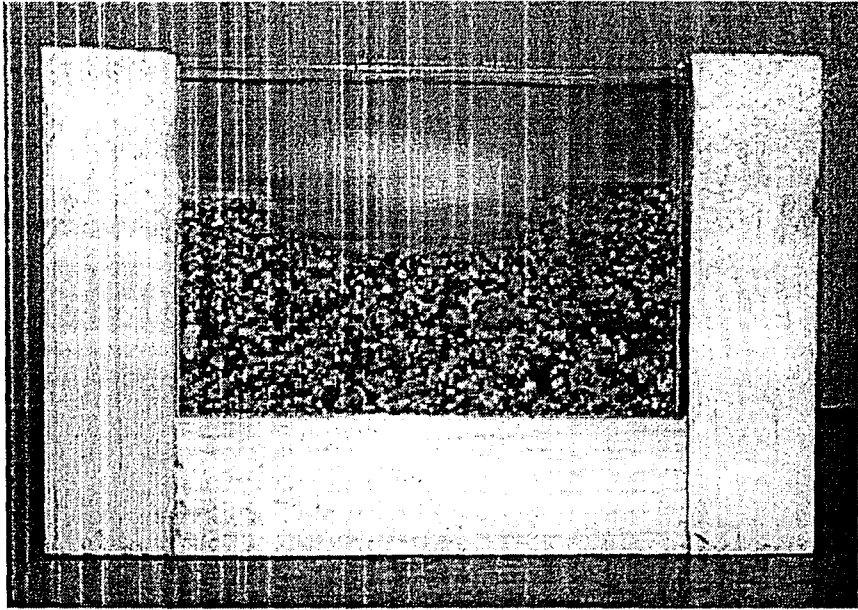


Figure 3.5 Soil Sample

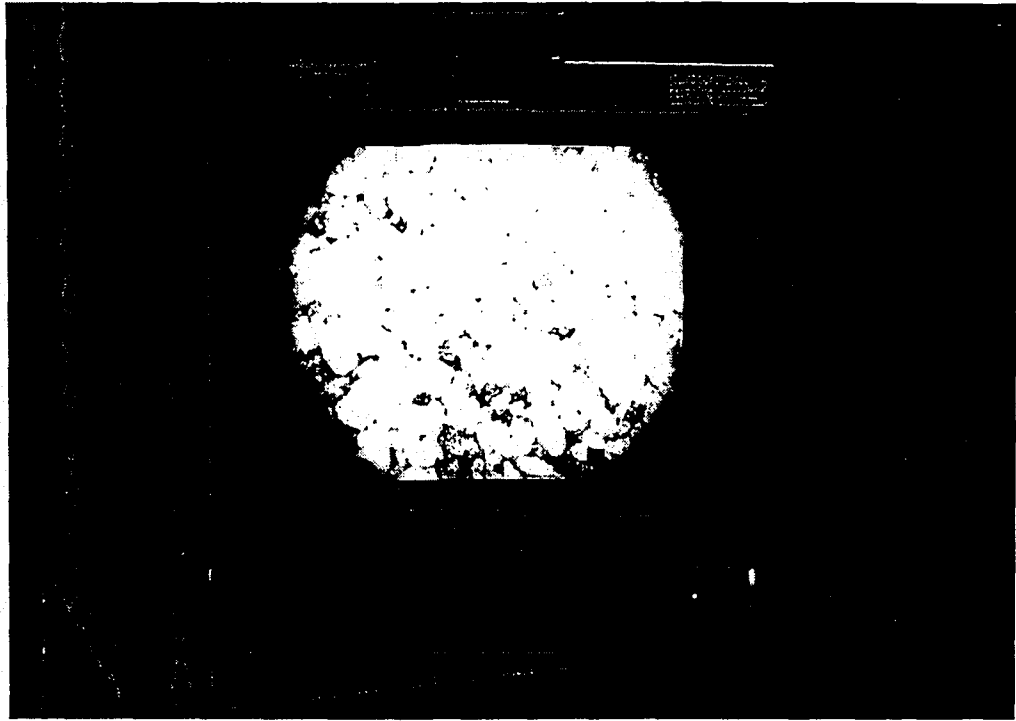


Figure 3.6 Video Monitor

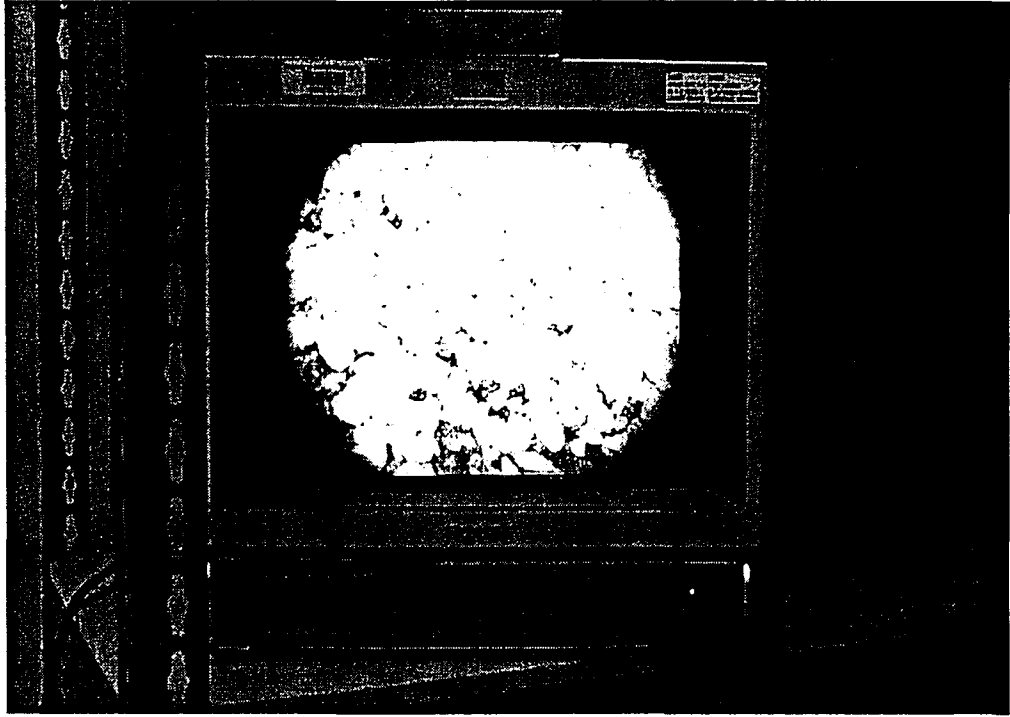


Figure 3.6 Video Monitor

Chapter 4: Digital Image Processing Methods.

4.1 Introduction

There are several approaches or techniques for processing the images of soil samples obtained. Some of the relevant ones are described briefly. The most suitable method was determined and used for this research.

The first step to follow after acquiring the images is to filter the images for any noise present if necessary. The filtered images are then subjected to edge detection techniques, whereby each particle is separated from adjacent particles and identified. The diameter of each particle is determined and the grain size distribution of the sample determined.

4.2 Enhancement operations

Images always contain noise. Noise is defined as any undesirable signal, disturbance, or changes in signal that mask the desired information. Noise can be present in an image due to several reasons like improper illumination source, improper sampling frequency, distortions caused by the imaging systems, etc. Filters are used to enhance the images and discard the irrelevant information. The filtering operations to be used on any image are application specific and generally subjective. Some of the common image enhancement operations are described below.

4.2.1 Histogram sliding and stretching

A histogram is the depiction of the distribution of the gray-levels in an image. A low contrast image would have the distribution concentrated in a small area. By manipulating the histogram, the image can be enhanced. Sliding of the image is simply adding (or subtracting) a constant value from the gray-scale value of each pixel. Sliding the histogram produces the effect of adding constant brightness (or darkness) to an image. Histogram stretching is the multiplication (or division) of a constant value to all the pixel values. These operations result in a "better" image with well-balanced contrast characteristics. However, it must be noted that a visually "better" image may not be the goal of the operations. For example, a high contrast image may be necessary to highlight a small feature of interest in the image. The ultimate goal of use of the image must always be kept in mind before applying any enhancement operations to an image. Care should always be taken to make sure no important information is lost in the filtering operations.

4.2.2 Low-Pass Filtering

A low-pass filter attenuates the high-frequency components in an image, leaving behind only the low frequency components. The edges in an image are usually characterized by high frequency components. The deletion of these high frequency components produces an effect of "smoothing" or blurring the image. A low-pass filter is used to filter noise spikes with high frequency components. A typical 3x3 low-pass filter is shown in Figure 4.1(a). Note that this filter doesn't alter the image in regions of constant brightness. (Baxes, 1994)

$1/9$	$1/9$	$1/9$
$1/9$	$1/9$	$1/9$
$1/9$	$1/9$	$1/9$

Figure 4.1 (a) Typical Low-Pass Filter

-1	-1	-1
-1	9	-1
-1	-1	-1

Figure 4.1 (b) Typical High-Pass Filter

4.2.3 High-Pass Filtering

A high-pass filter produces an effect opposite to that of a low-pass filter. A high-pass filter attenuates the high frequency components of an image, leaving the low frequency components untouched. A typical 3x3 high-pass filter is shown in Figure 4.1(b). The filter produces the visual effect of sharpening the image. Any details blurred due to poor focusing or other reasons can be more apparent. It should be noted that just like a low-pass filter, a high-pass filter leaves the regions of constant brightness untouched. This filter is sometimes used to highlight the edges of objects within an image. (Baxes, 1994)

4.3 Image segmentation

A segmentation operation is any operation that highlights or in some way isolates individual objects in an image. The goal of segmentation is to simplify the image without discarding any relevant information. Segmentation methods can be either pixel-based or region based in the spatial domain. Segmentation can also be carried out in the frequency domain using Fourier transforms, Hough transforms, wavelets, etc. Some of these are discussed below.

4.3.1 Region Splitting and Merging

The basic idea behind this operator is that if some property of a region is not constant, the region should be split or if it is constant, it should be merged. Usually the operator begins with the entire image, splitting or merging it into its components. The

problem lies in deciding the property and when it is to be considered “constant”. The split and merge operator can be summarized as follows:

1. Consider the entire image as a single region.
2. Pick a region and if the property is not constant within the region, split the region into sub-regions.
3. Consider two or more neighboring regions. Merge the regions with the constant property.
4. Repeat this process until no further splitting can take place.

The disadvantages of using this method lie in selecting the correct property and the appropriate threshold for the property to be considered as constant over a region.

4.3.2 Watershed Edge Detection

This is a region-based edge-detection method. It is based on two fundamental morphological operations: erosion and dilation. The erosion operation reduces the size of a bright object, relative to its background (i.e. it erodes the object boundary). The overall brightness is also reduced. The dilation operation does the exact opposite. It brightens bright objects and thus makes them appear larger in size.

Opening is defined as an erosion operation followed by a dilation operation and *closing* is defined as a dilation operation followed by an opening operation. The opening operation darkens small objects and entirely removes single-pixel objects like noise spikes.

In case of watershed edge detection, an image is transformed such that the brightness intensity is depicted as the height of the three dimensional image. The

image is then complemented, so the bright parts of the image appear as valleys and the dark parts appear as crests or mounds. The image is then imagined to be inundated with water, thus filling the depressions. As the water level rises, the neighboring objects collect water independently and the pixels, which separate two neighboring water-bodies, are marked. These marked pixels are the dividing lines of the neighboring objects. (Castleman, 1994)

4.3.3 Second Derivative Operators

A plot of the distribution of gray-levels in an image is the brightness histogram. Any edge is usually associated with intensity changes (discontinuities) and thus can be detected in the derivative. This is the basis for most of the common edge detection filters such as Sobel, Prewitt, Canny, etc.

However, edges detected using the first derivative have thick boundaries, which may be crucial while measuring particle sizes. The solution to this is using the second derivative of the image intensity. The second derivative operators determine the local maxima in the gradient values and consider them as the edge points. The Laplacian operator is an example. However, the Laplacian operator is sensitive to noise so Laplacian of Gaussian (LoG) operator is usually used. This method first uses a Gaussian filter to reduce the noise in the image. It then uses the Laplacian operator in two dimensions. The edges are detected by zero crossings or using linear interpolation to estimate the edge. The disadvantages of this are that the Gaussian filtering usually smoothes the image, thus making edge detection more difficult.

4.3.4 Hough Transforms

The Hough transform is based on the principle that each point in the real space image is mapped as a sinusoid in the Hough space. Similarly, each point in the Hough space represents a line in the real space. Using these principles, the points at which two features in an image touch each other (edges of the features) can be detected. This is very useful in detecting images, which contain objects having straight-line edges. However, the size and dimensions of the Hough space used increases considerably with the complexity of the shape. In general, to define a circle in real space, requires a three-dimensional Hough space, since three points are required to completely define a circle. The process becomes very computationally intensive when irregularly shaped particles are considered.

4.3.5 Wavelets

Wavelets are functions that divide data into different frequency components and study each component at particular resolution. (Hwang et. al 1997). These are especially suitable for analyzing signals that vary at different resolutions. The basic principle is similar to Fourier transforms where a signal is approximated by superimposing sine and cosine functions.

The name *wavelet* comes from the requirement that they should always integrate to zero. (Singh, et. al. 1997) The signal is decomposed into a set of basis functions, called wavelets, which are obtained by scaling and translating a single *mother wavelet*.

There are two kinds of wavelet transforms: continuous and discrete wavelet transforms. The discrete wavelet transforms can be further subdivided as redundant discrete systems (frames) and orthonormal bases of wavelets. For edge detection purposes, the discrete wavelet transform is used, which searches for local minima and maxima in the wavelet domain. The orthonormal wavelets allow multi-resolution analysis so they are particularly suited for applications, which have features varying at different scales. The different examples of wavelet transforms are Haar wavelets, Morlet wavelets, Meyer wavelets, etc, named after the people who formulated these wavelets.

Using the wavelet transforms, the image is filtered to obtain a high-pass (wavelet function) and a low-pass (scaling function) component. The components are again subjected to high-pass and low-pass filtering which results in three detailing images and one low-pass residue. It should be noted that down sampling degrades the edge details so the edges are obtained at each stage before down sampling. (Rifaat et. al. 1997, Takaya et. al. 1993, Truchetet 1994 and Vermeul 1993). Thus, wavelets offer a flexible and easy method for edge detection and can be application independent. This process is indicated in Figure 4.2.

4.4 Feature Extraction

Feature extraction allows quantitative measurements to be made from an image in order to describe it numerically. Feature extraction uses techniques based on spatial features, edge detection, boundary extraction and contour following, shape features

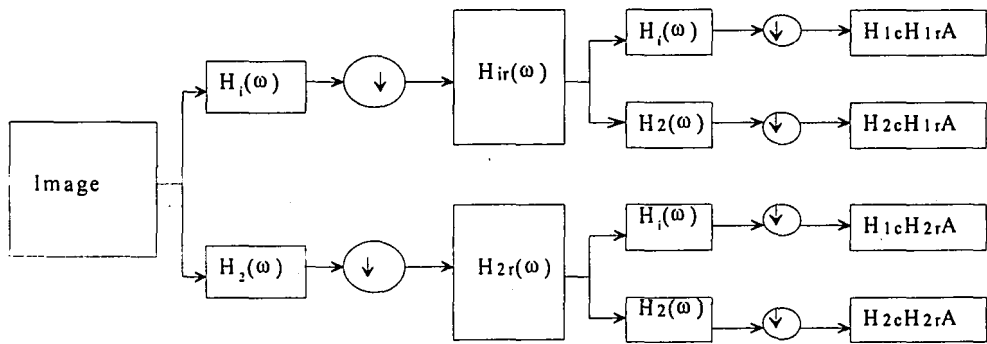


Figure 4.2 Sub-band decomposition using wavelets (from Wang, et. al.)

and textures, etc. There are various ways to describe the size of a particle. The most commonly used method is calculating the area of the particle and specifying an "effective diameter" assuming a circular particle of equal area.

4.5 Grain size distribution

On determining the effective diameter of the particles captured within the image, a grain size distribution is plotted. Although a true "grain size distribution curve" may not be plotted, the results should give a fair idea about the size distribution of the soil in the sample. It should be noted that this distribution is on a volume basis, unlike sieve analysis, which is on mass basis.

4.6 Summary

On the basis of the above applications and methods, it is proposed to characterize soil using imaging techniques. Images of statistically valid soil samples will be captured, the number of soil particles counted, the shape described (qualitatively) and measured (quantitatively), and the grain size distribution (gsd) of the soil plotted. Initially, the soil chosen will be uniformly graded and dry. Variations in the gsd, water content, etc. will be added later.

Chapter 5: Software Review.

5.1 Introduction

To implement the image processing techniques described in Chapter 3, we need to find a suitable software package, incorporating all the essential features. Stress is laid on the segmentation techniques offered by the package and its particle measuring capabilities. Other important factors include consideration of the platform on which the software operates and its cost.

While most of the software available have standard filters like Sobel, Prewitt, etc. programmed for edge detection, other segmentation techniques such as watershed edge detection and wavelet based segmentation are difficult to find.

5.2 Software

The different software discussed here are: Scion Image (Win 95/NT), Astra Image (Win 95/NT), Image Lab (Win 95/NT 4.0), Osiris (Mac/PC/Unix), Impuls Pickup (Win 95/NT), Khoros(Unix), and Matlab (Unix).

5.2.1 Scion Image

Scion Image works in a Windows 95 or Windows NT environment and has an in-built Sobel operator for edge detection. It performs a horizontal and vertical Sobel edge detection and combines the results by taking the square root of the sum of squares

of the derivatives. It has various other useful tools such as analyze the image, take measurements, etc., besides the usual image processing tools like erode, dilate, show histogram, etc. It uses images in the bmp and tiff format. It is available for free download at <http://www.scioncorp.com>. It is the Windows version of NIH Image, developed by National Institutes of Health for the MacOS.

5.2.2 Astra Image

Astra Image also works in a Windows 95 or 98 or NT environment. It has various edge-detection techniques built into it, such as Sobel, Prewitt, Laplacian, etc. A trial version of the entire package is used. It includes advanced features such as building custom filters, using Fourier Transform on the images, etc. Image processing in the frequency domain is also possible. It uses images in the jpg and bmp formats. The demo version is available at <http://www.phasespace.com.au/astraimage>. Phase Space Technology has developed Astra Image and the full (educational) version can be ordered on-line from this Australian company for A\$ 150 (approximately US\$99).

5.2.3 Image Lab

The demo version of Image Lab is available at <http://www.mcm-design.dk/imagelab.htm>. It works in Windows 95/ NT. However, the demo version of the software only uses files with extensions drw, or vts. It is developed by MCM Design, Denmark. The full version uses gif, jpg, tiff, etc. file formats and can be ordered on line for \$775 for a single user license.

5.2.4 Osiris

Osiris is software that runs on a Mac, PC or on a Unix machine. It has a built-in edge detector but no information about the type of detector is. It is mainly developed for applications to medical imaging. It lacks any substantial or useful image manipulation tools so it is not suitable for this research. It is available for free download at <http://www.expasy.ch/www/UIN/html1/projects/osiris/DownloadOsiris.html>.

5.2.5 Impuls Pickup

Impuls Pickup is an image processing software available at <http://www.impuls-imaging.com> for Windows 95/NT environment. More general versions of Pickup, called Vision S, Vision XL and Vision XXL can be purchased online. It uses the tif and bmp file formats. It uses a workspace environment, somewhat similar to Khoros. It uses Sobel and Prewitt edge detectors. Being a demo version, it does not provide the user with undo or redo operations (very inconvenient!).

5.2.6 Matlab

Matlab is a software that combines numeric computation with advanced graphics. It has application-specific group of files or functions termed as toolboxes. It also has a special toolbox dedicated to wavelets. Toolboxes such as the morphology toolbox (<http://www.mmorph.com>), wavelab (<http://www-stat.stanford.edu/~wavelab>), etc. developed by users is also made available on the web. The student edition of mmorph for Windows 95/98/NT and Linux and Solaris is available for a price of \$30.

However, the student version will only operate on images which are 128 * 128 pixels in size. The academic version costs \$349.

For the purpose of determining the edges within an image, filters like Sobel, Prewitt, Roberts and Laplacian of Gaussian (LoG) are available. The versatility of the package lies in the ability to allow a user to write his/her own Matlab functions or files. The official web site for Matlab is <http://www.mathworks.com>. It uses bmp, jpg, tif and other file formats.

5.2.7 Khoros

Khoros is a image-processing tool, which uses a workspace environment in a visual language called Cantata. It also uses the toolbox concept and also allows the user to program any function for his/her specific application. It has various built-in functions for image manipulation, enhancement, etc. It has Sobel, Roberts, Prewitt filters for edge detection. It also has the capability to manipulate the images using wavelet and Fourier transforms. The package as well as a tutorial to it is available via anonymous ftp at <ftp://ftp.dca.fee.unicamp.br/pub/khoros/Khoros2/contrib/toolboxes/dipcourse>. Also, the mmach toolbox (Mathematical Morphology toolbox) is available via anonymous ftp at <ftp://ftp.dca.fee.unicamp.br/pub/khoros/Khoros2/contrib/toolboxes/mmach>. Khoros uses files with extension kdf.

5.3 Other Segmentation techniques

The region splitting and merging technique is interactive. The user needs to define the region to begin the split and merge operations. The solution to this is to consider the entire image as one region. The other problem with this approach is defining the controlling property and the criteria for considering it as constant. This algorithm could be programmed in the Matlab or Khoros environment, in the absence of the toolbox facilities.

Watershed edge detection is a very suitable method for segmentation of images in which objects are very close to one another or touching each other. Khoros has a built-in function for the segmentation of an image with the watershed technique. The mmorph toolbox with Matlab also contains this feature along with blob labeling capabilities.

As discussed in the previous chapter, Hough transforms are computationally very intensive and hence will not be discussed here.

Edge detection using wavelets is a relatively new concept. Although a lot of the current research papers talk about this, not many software packages are available which incorporate this feature. A new toolbox for Matlab, called Wavelab has been developed for applications of wavelets to signal processing and image processing. Khoros also has a wavelet toolbox to implement the use of wavelets for image processing. These toolboxes need to be studied further.

5.4 Summary

◦ Selecting the software appropriate for a particular application needs more research. The ideal procedure to follow would be to analyze the images with known properties with the different packages and compare the known properties to those measured or predicted by the software. Here, the software have been discussed mainly from the point of view of edge detection techniques. Further studies regarding the effectiveness of the software in measuring the particles, needs to be investigated.

Chapter 6: Image Acquisition.

6.1 Introduction

Considering the criteria described in Chapter 5, the software Matlab (version 5.3, Mathworks) was chosen for the image analysis. The Image Processing Toolbox (version 2.2, Mathworks), Morphology Toolbox (SDC) and Wavelet Toolbox (version 1.2, Mathworks) were also used.

Five different soil samples were analyzed to test the image acquisition, image processing and particle counting systems. Two of these samples were uniformly graded soil samples, one gap-graded and two samples were well graded. The soil samples were labeled as follows:

Sample A: Uniformly-graded soil (passing sieve no. 8 and retained on sieve no. 16).

Sample B: Uniformly-graded soil (passing sieve no. 30 and retained on sieve no. 60).

Sample C: Gap-graded soil (soil passing sieve no. 30 and retained on sieve no. 60 absent).

Sample D: Gap-graded soil (soil passing sieve no. 8 and retained on sieve no. 16 absent).

Sample E: Well-graded soil.

It should be noted that the samples have been wet-sieved and dried in the oven for 24 hours. The wet sieving eliminates any fine particles (dust-sized) that may be present and which may corrupt the results. The results of the sieve analysis are shown in Figures 6.1- 6.5.

Sample A

Soil wt. (g): 3.006

Sieve No.	Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	% Finer
4	4.75	0	3.006	100
8	2.36	0	3.006	100
16	1.18	3.006	0	0
30	0.6	0	0	0
60	0.25	0	0	0
100	0.15	0	0	0
200	0.075	0	0	0
Pan				

Figure 6.1 (a) Sieve analysis for Sample A.

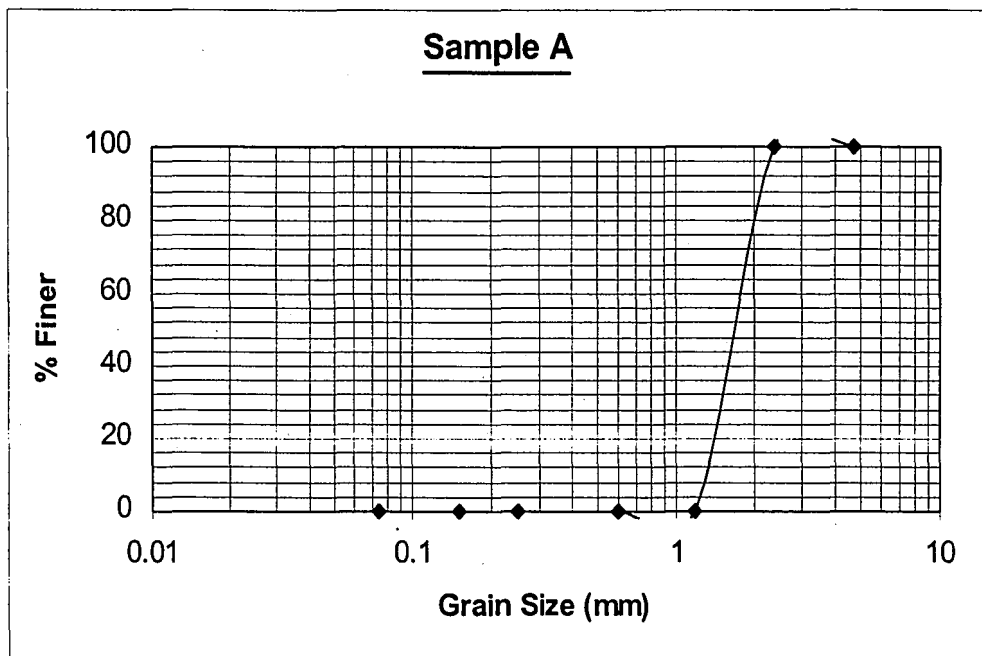


Figure 6.1 (b) Grain Size Distribution Curve for Sample A.

Sample B

Soil wt. (g): 2.162

Sieve No.	Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	% Finer
4	4.75	0	2.162	100
8	2.36	0	2.162	100
16	1.18	0	2.162	100
30	0.6	0	2.162	100
60	0.25	2.162	0	0
100	0.15	0	0	0
200	0.075	0	0	0
Pan				

Figure 6.2 (a) Sieve Analysis for Sample B.

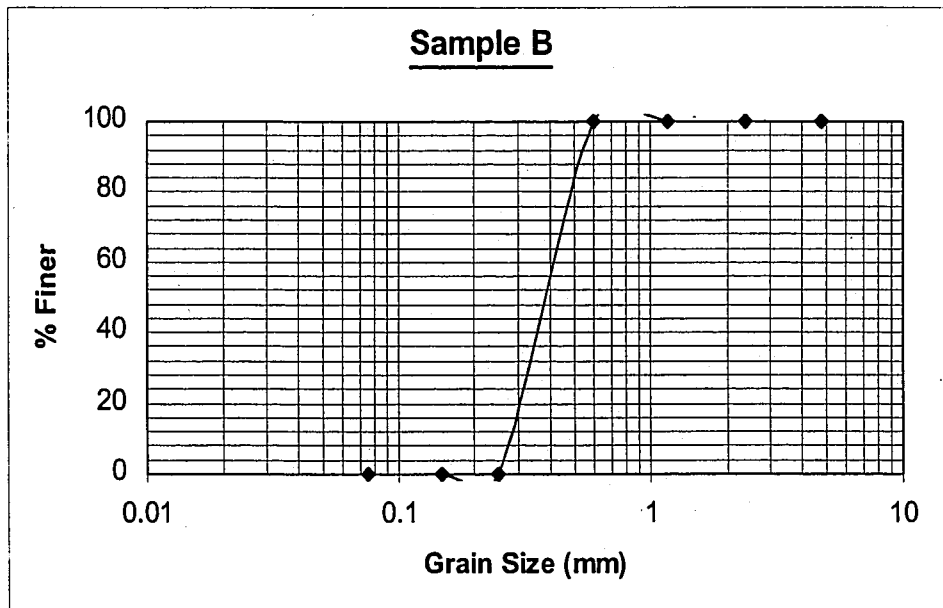


Figure 6.2 (b) Grain Size Distribution for sample B.

Sample C

Soil wt. (g): 2.532

Sieve No.	Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	% Finer
4	4.75	0	2.532	100.0
8	2.36	0.342	2.19	86.5
16	1.18	0.642	1.548	61.1
30	0.6	0.562	0.986	38.9
60	0.25	0	0.986	38.9
100	0.15	0.329	0.657	25.9
200	0.075	0.123	0.534	21.1
Pan				

Figure 6.3 (a) Sieve Analysis for Sample C.

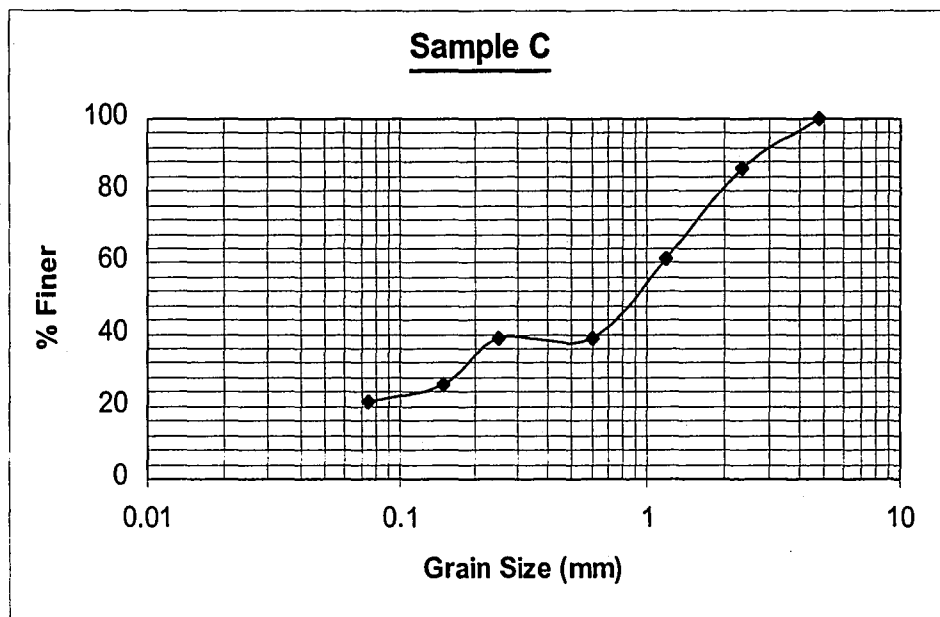


Figure 6.3 (b) Grain Size Distribution for Sample C.

Sample D

Soil wt. (g): 2.419

Sieve No.	Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	% Finer
4	4.75	0	2.419	100.0
8	2.36	0.416	2.003	82.8
16	1.18	0	2.003	82.8
30	0.6	0.375	1.628	67.3
60	0.25	0.484	1.144	47.3
100	0.15	0.644	0.5	20.7
200	0.075	0.114	0.386	16.0
Pan				

Figure 6.4 (a) Sieve Analysis for Sample D.

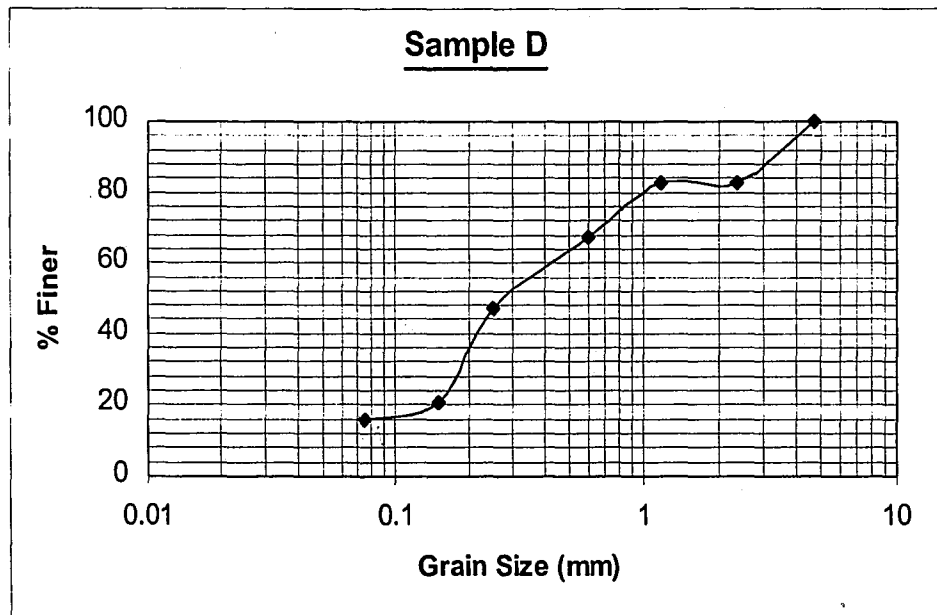


Figure 6.4 (b) Grain Size Distribution for Sample D.

Sample E

Soil wt. (g): 4.016

Sieve No.	Sieve Size (mm)	Mass Retained (g)	Mass Passing (g)	% Finer
4	4.75	0	4.016	100.0
8	2.36	0.677	3.339	83.1
16	1.18	0.481	2.858	71.2
30	0.6	0.796	2.062	51.3
60	0.25	0.748	1.314	32.7
100	0.15	0.631	0.683	17.0
200	0.075	0.193	0.490	12.2
Pan		0	0	0

Figure 6.5 (a) Sieve Analysis for Sample E.

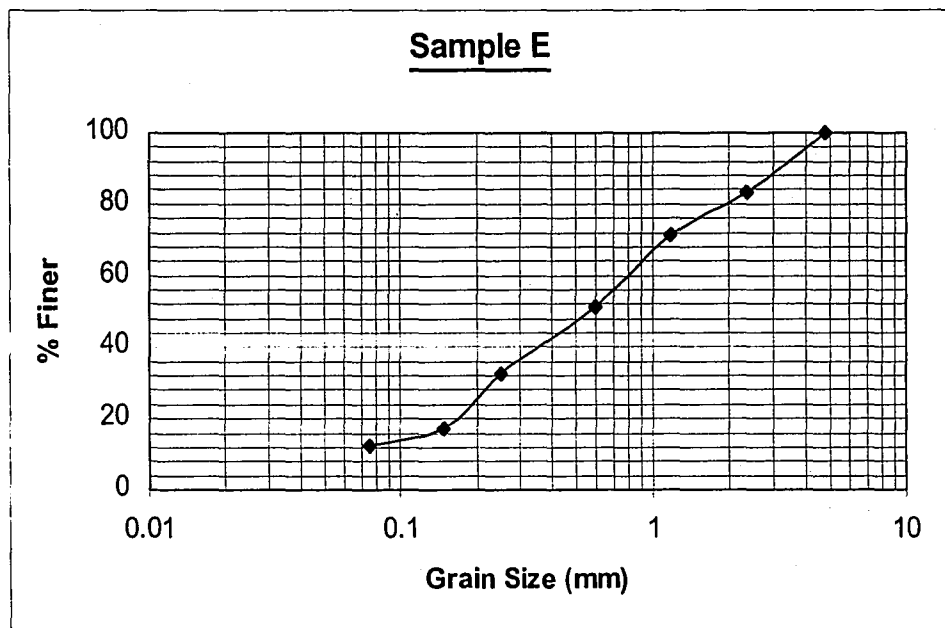


Figure 6.5 (b) Grain Size Distribution for Sample E.

6.2 Image Acquisition

Due to problems with the framegrabber and its compatibility with the operating system (Red Hat Linux 6.0), the images could not be acquired for the testing. However, for someone interested in carrying out this work further, the procedure and details are described below. All the samples should be imaged at three different levels of magnification, viz., low magnification, intermediate magnification and high magnification.

The low magnification can be achieved by using the 0.25X lens and the 0.5X adapter. This level of magnification covers the particles ranging in size from 0.8mm to 5 mm. It should be noted that each particle in the image should vary in size between 50 pix² and 2000 pix² (Raschke, 1996). The desired level of magnification is decided based on this guideline. To acquire the image at intermediate magnification level, the 2X lens and the 0.5X adapter are used. This level covers the particles ranging from 0.1mm to 0.66mm. The highest level of magnification can be achieved using the 2X lens and the 2X adapter. This level images the particles ranging in size from 0.025mm to 0.16mm. Thus, the entire spectrum of soil particles varying in size from 0.025mm to 5 mm can be detected and analyzed using this technique.

6.3 Image Analysis

The images obtained will have to be saved in a format that can be understood by the image analysis software, Matlab. The Image Processing toolbox and the Morphology Toolbox must be available. The images should be loaded into Matlab,

edge detection should be performed using watershed segmentation algorithm and finally blob labeling should be used to enumerate the particles and determine the size of each particle. The code for the algorithms can be found at the web sites for the Image Processing toolbox and the Morphology toolbox. The code can be tailored to suit the needs of the application by adding or editing code segments to the existing segments.

6.4 Results

The results obtained from the image processing and Morphology toolboxes could be exported to any plotting package or even plotted within Matlab itself to give the grain size distribution of the soil samples. These could then be compared with the results of sieve analysis. It should be noted that the discrepancies in the two results could be because of two possible reasons.

An important point to note is that the definition of "size" in both methods is different. Sieve analysis measures the intermediate dimension (neither the smallest nor the largest dimension) of the three-dimensional soil particle. The result is interpreted as the soil particle having the same size as a sphere of that radius.

For image processing, the size of the particle is measured based on a two-dimensional projection of the three-dimensional soil particle. Depending on the orientation of the soil particle and the two-dimensional plane of projection, the results obtained by image analysis of the same soil sample could vary. However, these variations will not be significant.

The other point of discrepancy is that sieve analysis is mass-based whereas image processing gives the grain size distribution of the sample based on percentage by volume. These should be noted while comparing the results of the two methods.

Chapter 7: Future Scope.

As stated in Chapter 6, it should be noted that the system described in this thesis is optimized for dry soils only. The testing was hence performed on dry soils only. For truly characterizing soils, the system should be versatile and should be able to analyze soils whether dry, partially saturated or fully saturated.

It should be noted that the image processing system only measures the grain size of the particles. While grain size is an important property of coarse-grained soil, the behavior of fine-grained soil is ruled by its mechanical properties like Atterberg limits. Thus, although the system can determine the grain size of fine-grained soil samples, their utility is limited to determining the percentage of clay or silt in the sample.

The segmentation methods used are not completely adequate. Important problems such as overlapping of particles need to be studied. Using Wavelets for edge detection seems to be the ideal solution to several problems related to edge detection. However, software that incorporates the use of wavelets for edge detection needs to be searched and studied.

The ultimate goal of the thesis would be to use the image processing system in the field during subsurface exploration. The big picture is using the system in conjunction with the SVP - Subsurface Vision Probe (Raschke, 1996). The SVP is a cone penetrometer (CPT) attached with two CCD cameras, which capture the soil images as the cone penetrates the soil. The inherent disadvantage of the CPT method –

the lack of a visual soil sample – is thus eliminated and the system automated. The system also needs to be developed from the point of view of acquiring these images and performing the analysis in real time. An ideal system would acquire the images, record them on a videotape, analyze them characterize the soil as the cone penetrates through the soil.

Future work would proceed with the aim to automate the entire process and eliminate human errors. The automation would not only make the process more objective, but also save time and hence, money.

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Wavelets: <http://www.amara.com/IEEEwave/IEEEwavelet.html>

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Vita.

Ms. Kshitija Naphade was born to Capt. Sudheer Naphade and Dr. Pushpa Naphade on March 8, 1976 in the Indian city of Mumbai. She attended Indian Education Society's English Medium school and graduated from D. G Ruparel College (Mahim, India) in the Science discipline. She acquired a degree in Civil Engineering (Bachelor of Engineering) from Sardar Patel College of Engineering, (University of Bombay).

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The author has now acquired a job with Langan Engineering and Environmental Services at Elmwood Park, New Jersey.

**END OF
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