International Journal of Engineering Research and Reviews ISSN 2348-697X (Online)
Vol. 3, Issue 3, pp: (1-15), Month: July - September 2015, Available at: www.researchpublish.com

The Relationship between the Physical Properties of Soil and Shape Factors of its Fragmented Aggregates: A Two-Dimensional Digital Image Processing and Analysis Approach

[1]Benjamin Yiediboe, [2]HE Lin, [3]Yuan Jian, [4]Liu Cong, [5]Wang Zhenliang

[2]Associate Professor, [34]PhD Students, [15]Master Students
[2345]Key Lab of Structures Dynamics Behavior and Control of the Ministry of Education
[1]Department of Geotechnical Engineering, School of Civil Engineering
[12345]Harbin Institute of Technology, Harbin, P.R.China, 150090

Abstract: **Soil physical properties are used for soil classification and hence serve as the first estimator of almost every mechanical and hydrologic soil behavior, but the usual laboratory testing method of estimating these physical properties is time consuming, burdensome, and somehow subjective, hence posing a challenge to geotechnical engineers and soil lab technicians. To minimize these shortfalls to an acceptable level and make the determination of soil physical properties more objective, this study utilized digital image processing and analysis (DIP&A) approach to establish relationships between the physical properties of soil (water content, density-wet bulk and dry, porosity, and void ratio) and the image feature of its fragmented aggregates identified as shape factors and recognized as aspect ratio and roundness in the study. Shape factors are used to describe the overall geometric characteristics of a particle. In this study, samples of soil were collected and laboratory test performed as per the American Society of Testing and Materials (ASTM) Standards to determine the physical properties and the same samples fragmented into appropriate sizes and their images acquired for image processing and analysis to determine the image feature. The physical properties of soil were statistically correlated and regressed against the image feature using appropriate regression model with the correlation coefficient (r) as the basis of the correlation. The r value varies from 0.5 to 0.6. The outputs of the regression analysis were curvilinear models that represent the relationship between soil physical properties and shape factors. The results of the digital image analysis were verified by conducting laboratory test and image analysis of soil sample collected from different site other than the one previously used to develop the relation models and the new values of the validated sample replaced in the developed models, resulting in a reasonable average percent error that varies from 1.05% to 3.57% between conventional laboratory testing and the proposed new method-DIP&A. The results indicate that DIP&A method proposed in the study appears to be a useful and promising method for estimating the physical properties of soil and was also shown to be a valuable tool for quantifying the geometric properties of soil aggregates.**

Keywords: **Soil, physical properties, fragmentation, digital image processing, shape factors.**

I. INTRODUCTION

Soil is an important aspect of nature that plays a dominant role to the growth and development of mankind. It is commonly defined as the surface of the earth that is not rock, air, or water. The precise definitions of soil may vary in various areas of specialization in terms of interest and need. Remarkably, it is primarily associated with agricultural or engineering purposes and this can be seen in its definitions, classification systems, and research. [1] defined the agricultural definition of soil as "a dynamic natural body on the surface of the earth in which plants grow, composed of mineral and organic materials and living forms". For engineering purposes, [2] defined soil as the un-cemented aggregate of mineral grains and decayed organic matter (solid particles) with liquid and gas in the empty spaces between the solid particles. It is used as a construction material in various civil engineering projects, and it supports structural foundations. Thus, it is very important and necessary to study the properties of soil such as its origin, grain-size distribution, water content, density, porosity, void ratio, hydraulic conductivity, compressibility, shear strength, load-bearing capacity and water-soil interaction. Determining these physical properties to estimate the strength of soil is one of the primary goals of geotechnical engineering. Nevertheless, geotechnical engineering is based mostly on empirical relations. The physical properties of soil are used for soil classification and hence serve as the first estimator of almost every mechanical and hydrologic soil behavior. The most widely used method for determining these properties is through laboratory experiments. Despite the fact that these standard test methods are physically burdensome, expensive, dusty, and somehow noisy, geotechnical engineers and soil laboratory technicians are still glued to the traditional and prevalent laboratory method of obtaining these properties. The data obtained from these various laboratory tests are highly subjective, which further complicates the existing variability in soil conditions over space and time [3].

DIP&A techniques have been extensively utilized in many disciplines of science and engineering. Medical Science uses it for tumor detection, DNA typing. In Criminology, it is used for fingerprint matching. Many Departments of Defense and Intelligence worldwide utilized DIP&A for target acquisition and guidance [3], [4], [5]. Upon studying the use of DIP&A techniques in various fields, it can be reasoned that there are applications in geotechnical engineering as well [6]. Recent geotechnical and engineering geology literature is abundant on the applications of digital image-based analysis in areas such as site characterization [7], mass characterization [8], particle characterization [9], motion and deformation [10].

Moreover, many studies have outlined the impact of particle shape or shape factors on the technical properties of soil material and boundless aggregates [11]. Some properties affected by particle shape are e.g. internal friction angle, porosity, void ratio, hydraulic conductivity, and permeability [12], [13]. A great deal of studies have been conducted utilizing the use of DIP&A to correlate soil physical properties to its image features, but however there is no comprehensive study that has established relationships between the shape factors of fragmented soil aggregates and the water content, wet bulk density, dry density, porosity and void ratio. Up to present, there has been little or no attempt to adopt a method to estimate the physical properties of soil using DIP&A. Consequently, this study was undertaken to establish relationships between soil physical properties and the shape factors of its fragmented aggregates adopting DIP&A approach.

II. MATERIALS AND METHODS

The steps adopted in this research to estimate the physical properties of soil through DIP&A are presented as followed. Fig. 1 illustrates the flow chart of the methodology of the study.

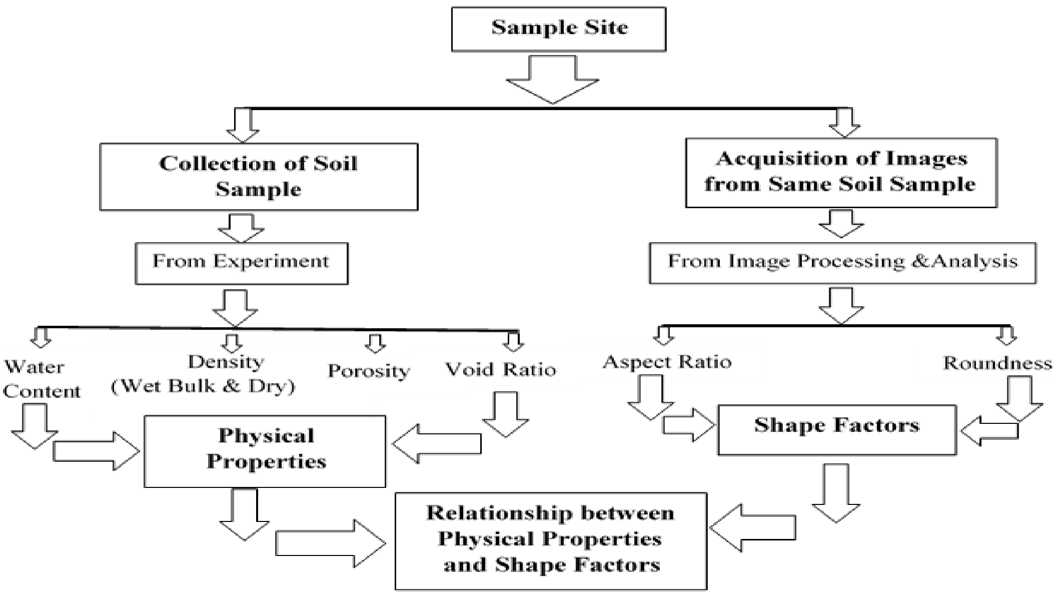


Fig. 1: Flow chart of the study methodology

2.1 Collection of Soil Samples:

Samples of soil were collected from pits spaced 60cm apart at a depth of 20cm from a site (45º45'16.16"N, 126º40'33.35"E) about 500m from the School of Civil Engineering, Harbin Institute of Technology, Harbin, P.R. China. The core method and the standard procedures of extracting samples from the ground as designated in [14] were adopted. It should be pointed out that all of the drive cylinders used for the collection of the soil samples had the same dimensions as stated herein and met the area ratio of 10.25% requirement as set forth by [15] for drive samplers (should not exceed 10% to 15%) as defined by Equation 1. To avoid samples disturbance, the samples were wrapped with aluminum foil placed in ziplock bags and taken to the Geotechnical Laboratory of the above mentioned institution for testing and image acquisition.

$$Ar = \left[\frac{De^2 - Di^2}{Di^2} \right]$$

(1)

Where:

Ar = area ratio, %

De = maximum external diameter of the drive sampler, 6.3cm

Di = minimum internal diameter of the drive sampler at the cutting edge, 6cm

2.2 Experimental Procedures:

The experimental procedure followed is as per the ASTM standard laboratory procedures for the determination of density [14], [16], water content [17]. From the test, the wet bulk density (ρ_d) and water content (ω) were determined. The dry density, porosity, and void ratio were not measured directly but were determined from the relationships as shown in equations 2, 3, and 4 respectively.

$$\rho_d = \frac{\rho_b}{(1+\omega)}$$

(2)

Where:

ρ_d = dry density, g/cm^3

$$\eta = \left(1 - \frac{\rho_b}{\rho_s} \right)$$

(3)

Where:

η = porosity of each soil samples

ρ_s = particle density, assuming to be 2.65 g/cm^3

$$\varepsilon = \frac{V_a}{V_s} = \frac{V_a}{V - V_a} = \frac{\eta}{1-\eta}$$

(4)

Where:

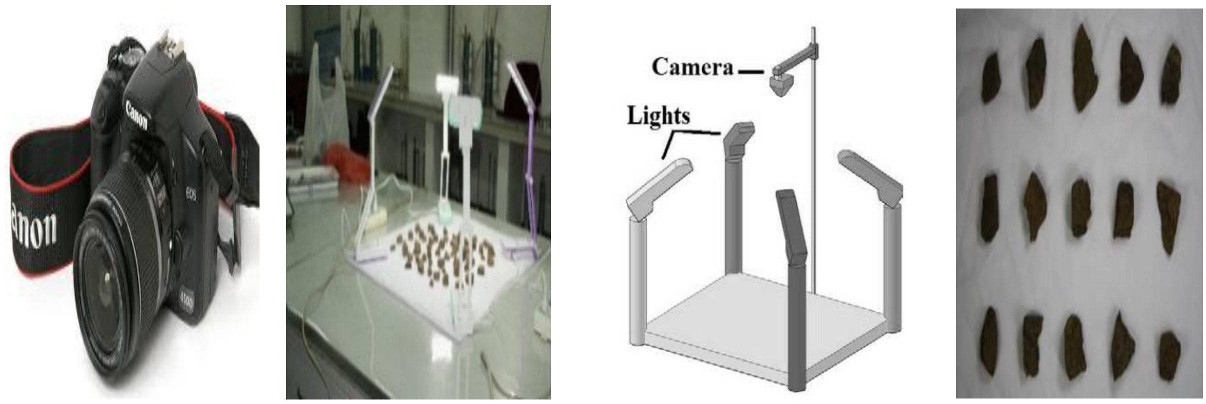
V_a = volume of void (air) in a soil sample, cm^3

V_s = volume of solid in a soil sample, cm^3

V = total volume of soil in a soil sample, cm^3

2.3 Image Acquisition:

The process of digital image processing and analysis starts with the capturing of a digital image (usually referred to as imaging) followed by its storage, transmission, processing, and analysis of the image by a computer to extract information or features of interest [18]. It is important to note that the selection of an appropriate image procedure is a compromise of price, equipment availability and limitations, sample preparation, and image processing requirements to obtain acceptable results. The fact that a soil's tendency to aggregate is increasing with decreased particle size and increased water content, makes it important to get the soil dry before performance of the image processing and analysis [19]. Natural soils are mixtures of solid grains and aggregates. A soil aggregate is "a group of primary soil particles that cohere to each other more strongly than to other surrounding particles". Soil aggregates are formed through the combined action of aggregation and fragmentation processes. The breaking of soil aggregates into smaller pieces or fragments is called fragmentation and this process is usually found in nature occurring due to external stresses [20]. However, for the purpose of this study, each collected soil samples was manually fragmented into fifteen appropriate sizes (see Fig. 2d) and spread over twelve (12) different tables for acquiring of soil images. The camera (see Fig. 2a) used was EOS 450D, is a 12.2-megapixel DSLR camera that is part of the Canon EOS line of cameras equipped with a macro lens with a focal length of 55mm. The equipment used for image acquisition was arranged as shown in Fig. 2b. The equipment for taking pictures of soil were set up by mounting a camera on a photographic stand as shown in Fig. 2c. The camera was adjusted at a height of 25cm and each image taken vertically above the sample tray to obtain a satisfactorily large measurement area and adjusting the light sources so that no shading of any object be reflected on the sample tray. A white cotton cloth was placed on the beneath the fragmented soil particles to obtain a better contrast between the soil particles and the background pixels. The imaging of the soil samples were preferably done at night to reduce the noise content that may have an impact on the desire results. Four fluorescent light sources were positioned at the four edges of the tray as seen in Fig. 2b to make the soil particles more visible for digital measurement and the flash of the camera was not utilized in the entire process [21].



(a) **(b)** **(c)** **(d)**

Fig. 2: (a) A pictorial of the used digital camera (b) A pictorial of the equipment setup (c) Schematic diagram of the image analysis systems [21] (d) Final output of the captured soil image for processing and analysis

2.4 Image Processing and Analysis (DIP&A):

Digital image processing and analysis is concerned with the transformation and analysis of pictures by a computer. Taking into consideration the guidelines on image manipulation presented by [22], three essential image processing steps were utilized: Image coding, Image processing, and Image analysis. The used image analysis program was ImageJ. In most studies that involve image processing, several commercial image processing programs (Adobe Photoshop, Image Pro, Matlab, etc.) are used for particle analysis but the licensing fees and computer hardware poses severe limitations. ImageJ is developed and written in Java by Wayne Rasband of the U.S. National Institute of Health and is freely available in the public domain. Fig. 3 illustrates the image processing and analysis work flow diagram used in this work.

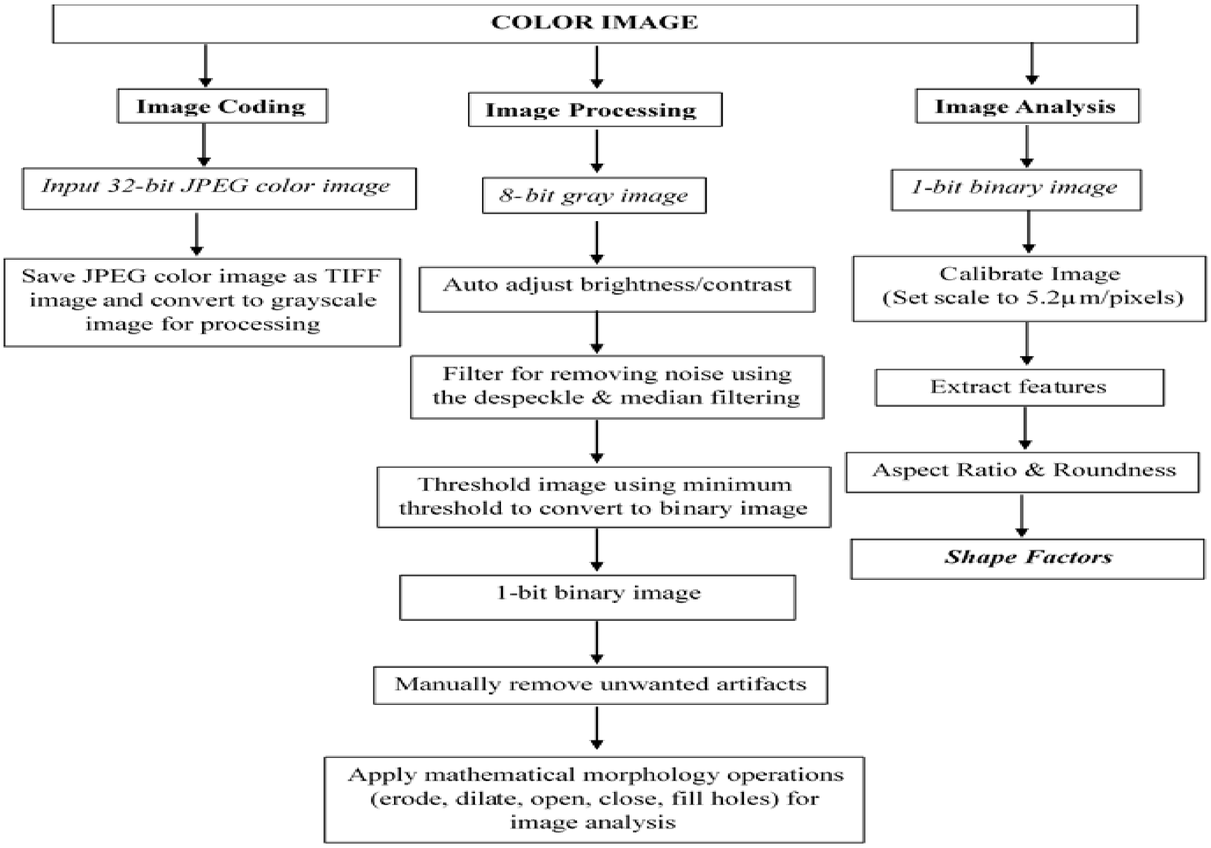


Fig. 3: Workflow diagram of the image processing and analysis

2.4.1 Image Coding:

Image coding involves inputting an image into an image processing software for processing and analysis.

2.4.1.1 Colour (RGB) Images:

The output of the camera used was a 4272 × 2848 pixels RGB JPEG color images shown in Fig. 4a. For this, one type of lossy compression and one type of lossless compression were used. Considering the fact that JPEG format uses lossy compression that leads to severe artefacts that are not compatible with quantitative analyses and TIFF format is a lossless compression that is the only format that saves spatial and density calibration, the JPEG format images were used for storage (opened as JPEG) and the TIFF format images used for processing and analysis (save as a TIFF before converting to grayscale images).

2.4.2 Image Processing:

Image processing involves the conversion of 32-bit RGB color images to 8-bit grayscale images, manipulation of the 8-bit gray images to enhance (removal of noise and image artefacts) their quality and then converting the enhanced gray images to black and white (binary images) which are then subjected to mathematical morphology algorithms (erode, dilate, open, close, fill holes, outline) for analysis.

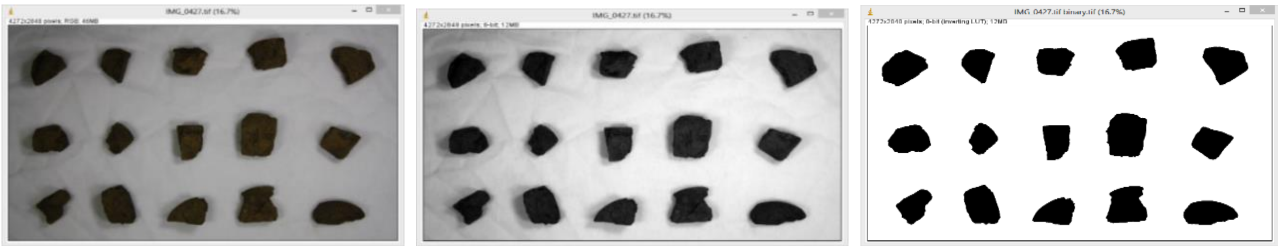
2.4.2.1 Grayscale Images:

32-bit TIFF color (RGB) images were converted to grayscale in ImageJ using the command; Image>Type>8-bit utilizing the formula: $grey = (red + green + blue)/3$ *or* $grey = 0.299 \times red + 0.587 \times green + 0.114 \times blue$. The grayscale images shown in Fig. 4b were processed to correct image defects and for image enhancement. Steps involved in this stage of the process included brightness/contrast adjustment, filtering for noise removal, and finally thresholding.

2.4.2.2 Binary Images:

The final step is the conversion of grayscale image to binary (black and white) image and is called thresholding. This is a point transform process that is designed to select the pixels within a range of brightness values that belong to the foreground (black) and reject all of the other pixels in the background (white). It produces a binary image presented in

Fig. 4c from a grayscale image by setting pixel value values to 1 or 0 depending whether they are above or below the threshold value. Raw binary images can contain a substantial number of artifacts caused by fractured grains and foreign matter embedded within the soil matrix which appears as holes or chips within the soil particles. Those artefacts were manually corrected with a pointer and drawing tool suite available in ImageJ. The process of correction is tedious, prone to errors, and is not practical for larger images. Alternatively, another class of automated editing procedures based on neighborhood relationships from a field known as mathematical morphology [23] employed. In digital image processing, mathematical morphology is used as a means to identify and extract meaningful image descriptors based on properties of form or shape within the image. The key morphological operators utilized in this work are erode, dilate, open, close, and fill holes/region filling. It is worth noting that watershed segmentation command was not used in this work since the particles of fragmented soil aggregates were manually separated before the acquisition of the images.



(a) (b) (c)

Fig. 4: (a) 32-bit TIFF color (RGB) soil image (b) 8-bit grey soil image (c) 1-bit binary image of fragmented soil for analysis

2.4.3 Image Analysis:

Image analysis is the process that allows quantitative measurements to be made from an image in order to describe it numerically. The binary images were analyzed using the analyze menu in ImageJ. This menu contains commands related to statistical measurements on image data, profile and histogram plotting, and plugins related to image analysis. The first step in any image analysis technique is to calibrate the image in terms of physical measurement units (e.g. for this study, µm). This step ensures clear representation of physical measurement units in terms of pixels on an image. The scale of the images was set to 5.2pixels/µm as per the specification of the used camera. The scale can also be set by referencing the resolution of the image. For instance, the acquired images had a resolution of 72 dpi, which can be used to set to scale to 72pixels/inch and acquired the same result. Measurements performed on the binary images generated information about the fragmented soil aggregates' area, perimeter, and shape factors (aspect ratio and roundness). In this study, the average shape factors of each soil sample were used in the analysis as shown in TABLE IV. Table I shows the results of the shape factors of the validated soil sample and this process is applied to the rest of the samples used in the study.

2.5 Shape Factors:

In this study, the word shape is used to describe the soil fragmented aggregates overall geometry. To define the particle form (morphology), in order to classify and compare grains, many measures have been taken into consideration (axis lengths, perimeter, surface area, volume, etc.). The shape factors used in this study are described below.

2.5.1 Aspect Ratio:

The aspect ratio (AR) of a particle is the ratio of the particle's major axis to its minor axis and is defined by Equation 5 and shown in Fig. 5:

$$AR = \frac{\text{Major Axis}}{\text{Minor Axis}} \qquad \text{(ImageJ)}$$

(5)

2.5.2 Roundness:

Roundness (Ro) refers to the sharpness of the corners and the edges of a particle. More commonly, the roundness is calculated using Equation 6. Roundness varies between 0.1 and 0.9. A value greater than 0.6 indicates high roundness, between 0.4 and 0.6 indicates medium roundness, and less than 0.4, low roundness [24];

$$Ro = \frac{4 \times Area}{\pi \times (Major\ Axis)^2} \quad or \quad Ro = \frac{1}{AR} \qquad \text{(ImageJ)}$$

(6)

Fig. 5: Schematic of shape factors [19]; A_p = Area of particle, P_p = Perimeter of particle

TABLE I: RESULTS OF THE SHAPE FACTORS OF THE VALIDATED SAMPLE

Soil Particle No.	Area, µm^2	Perimeter, µm	Major Axis	Minor Axis	Aspect Ratio	Roundness
1	4793.08	311.27	95.44	63.94	1.49	0.67
2	4219.90	269.43	84.51	63.58	1.33	0.75
3	2599.00	217.72	76.92	43.02	1.79	0.56
4	4611.35	277.37	85.72	68.44	1.25	0.80
5	3031.84	233.11	75.21	51.32	1.47	0.68
6	5940.16	326.04	100.83	75.01	1.34	0.74
7	4324.59	272.68	78.17	70.44	1.11	0.90
8	4213.98	271.16	91.43	58.68	1.56	0.64
9	4312.80	280.76	93.49	58.73	1.59	0.63
10	3980.84	270.67	84.86	59.73	1.42	0.70
11	5285.13	298.66	94.08	71.53	1.32	0.76
12	5272.74	298.56	91.59	73.30	1.25	0.80
13	3188.94	258.96	63.81	63.63	1.00	1.00
14	2956.62	228.07	69.59	54.09	1.29	0.78
15	4355.36	285.56	94.92	58.42	1.62	0.62
				Average	**1.39**	**0.74**

III. RESULTS AND DISCUSSION

3.1 Experimental Results:

TABLE II shows the results of the laboratory experiments.as per the ASTM standards. From these results as shown in TABLE III, the minimum and maximum values of porosity and void ratio were 0.20 and 0.33; 0.25 and 0.49 respectively which indicate that the type of soil used for the experiment was clayey sand and under the United Soil Classification System, it is denoted as SC [25].

TABLE II: EXPERIMENTAL RESULTS OF SOIL SAMPLES TESTING

Samples	Water Content, %	Wet Bulk Density, g/cm^3	Dry Density, g/cm^3	Porosity	Void Ratio
S-1	13.88	1.92	1.69	0.27	0.38
S-2	12.97	1.80	1.59	0.32	0.47
S-3	13.72	1.85	1.63	0.30	0.43
S-4	12.95	1.89	1.67	0.29	0.40
S-5	14.11	1.95	1.71	0.26	0.36
S-6	17.30	1.81	1.54	0.32	0.46
S-7	11.24	1.77	1.59	0.33	0.49
S-8	14.95	1.83	1.59	0.31	0.45
S-9	15.43	2.13	1.85	0.20	0.25
S-10	15.52	2.09	1.81	0.21	0.27
S-11	17.30	2.13	1.82	0.20	0.25
S-12	15.97	2.01	1.73	0.24	0.32

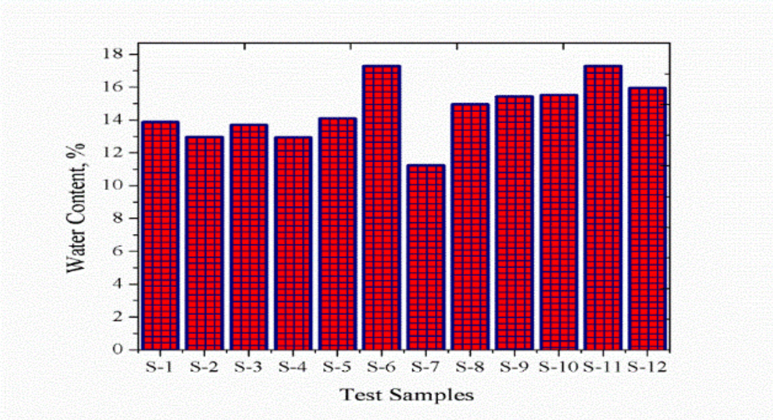


Fig. 6: Variation of water content of the tested soil samples

Fig. 6 reveals that all the studied soil samples have water content greater than 12% except sample S-7. Comparing dispersion among different soil properties, it is convenient and appropriate to express variance free from units of measurements. Coefficient of variation (CV) which is the ratio of standard deviation (Std. Dev.) to the mean is useful and meaningful index to compare the variability. From TABLE III, the CV of some properties of the soil samples were all below 10%. It is generally believed that the CV below 10% represents a weak variability [26], therefore the wet bulk density and dry density of the soil samples have very weak variability, while that of water content, porosity and void ratio exhibit strong variability.

TABLE III: DESCRIPTIVE STATISTICS OF SOME PROPERTIES OF THE STUDIED SOIL

Soil Properties	Min	Max	Mean	Std. Dev.	CV ,%	95% CI
Water Content ,%	11.24	17.30	14.61	1.82	12.46	14.61±1.03
Wet Bulk Density, g/cm^3	1.77	2.13	1.93	0.13	6.74	1.93±0.07
Dry Density, g/cm^3	1.54	1.85	1.69	0.10	5.92	1.69±0.06
Porosity	0.20	0.33	0.27	0.05	18.52	0.27±0.03
Void Ratio	0.25	0.49	0.38	0.09	23.68	0.38±0.05

3.2 Results of DIP&A:

The purpose of the DIP&A is to determine the shape factors (aspect ratio and roundness) of the fragmented soil aggregates.

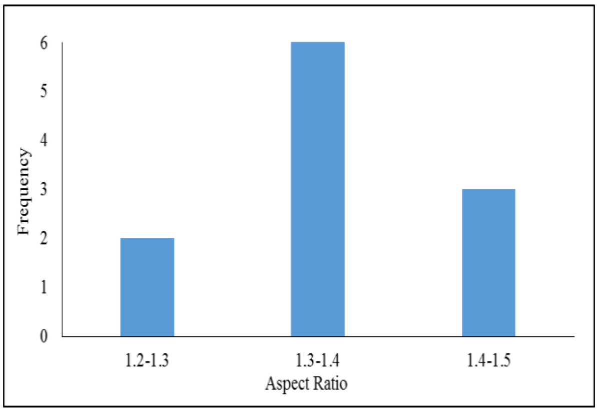
3.2.1 Shape Factors

The mean value of each soil sample shape factors was accepted as the final result for the soil particle shape factors as displayed in TABLE IV. Using a 2D image analysis setup consisting of only a top camera and capturing an image of each fragmented soil sample would not be effective in distinguishing the 3D shapes of the soil solids. In this study, only the top view of the fragmented soil aggregates was obtained and the front view (thickest portion) was not acquired which may influence the results of the shape factors.

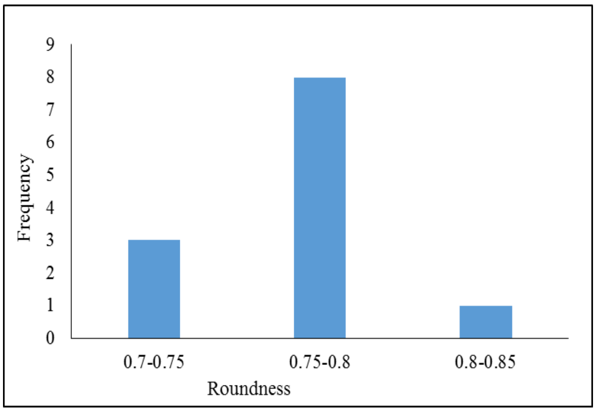
TABLE IV: RESULTS OF SHAPE FACTORS OF THE STUDIED SOIL

	Average Shape Factors	
Samples	Aspect Ratio	Roundness
S-1	1.26	0.80
S-2	1.37	0.75
S-3	1.41	0.72
S-4	1.35	0.76
S-5	1.42	0.73
S-6	1.23	0.83
S-7	1.42	0.73
S-8	1.34	0 .77
S-9	1.36	0.75
S-10	1.36	0.75
S-11	1.35	0.76
S-12	1.30	0.79

It can be stated that the studied fragmented soil samples used have high roundness [40] as demonstrated in Fig. 7b.



(a)



(b)

Fig.7: Soil samples shape factors histogram

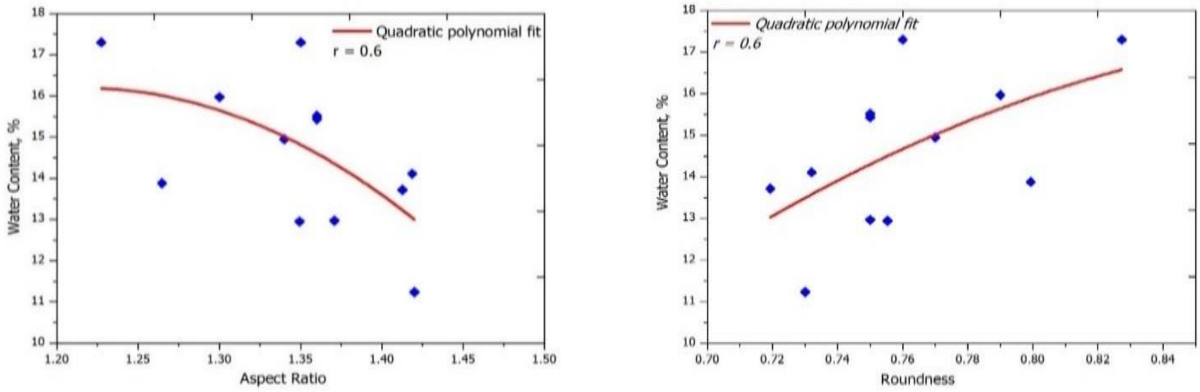
TABLE V: SOME STATISTICAL PROPERTIES OF THE STUDIED SOIL SHAPE FACTORS

		Shape Factors	
Sample	Statistical Properties	Aspect Ratio	Roundness
S-1	Std. Dev.	0.13	0.08
	CV, %	10.32	10.00
S-2	Std. Dev.	0.23	0.13
	CV, %	16.79	17.33
S-3	Std. Dev.	0.20	0.10
	CV, %	14.18	13.89
S-4	Std. Dev.	0.21	0.10
	CV, %	15.56	13.16
S-5	Std. Dev.	0.32	0.13
	CV, %	22.54	17.81
S-6	Std. Dev.	0.16	0.10
	CV, %	13.01	12.05
S-7	Std. Dev.	0.34	0.14
	CV, %	23.94	19.18
S-8	Std. Dev.	0.28	0.13
	CV, %	20.90	16.88
S-9	Std. Dev.	0.20	0.11
	CV, %	14.71	14.67
S-10	Std. Dev.	0.22	0.11
	CV, %	16.18	14.67
S-11	Std. Dev.	0.20	0.11
	CV, %	14.81	14.47
S-12	Std. Dev.	0.23	0.12
	CV, %	17.69	15.19

As shown in TABLE V, the CV of the values of aspect ratio and roundness ranges from 10.32% - 23.94% and 10.00% - 19.18% respectively suggesting the variability of these values were strong.

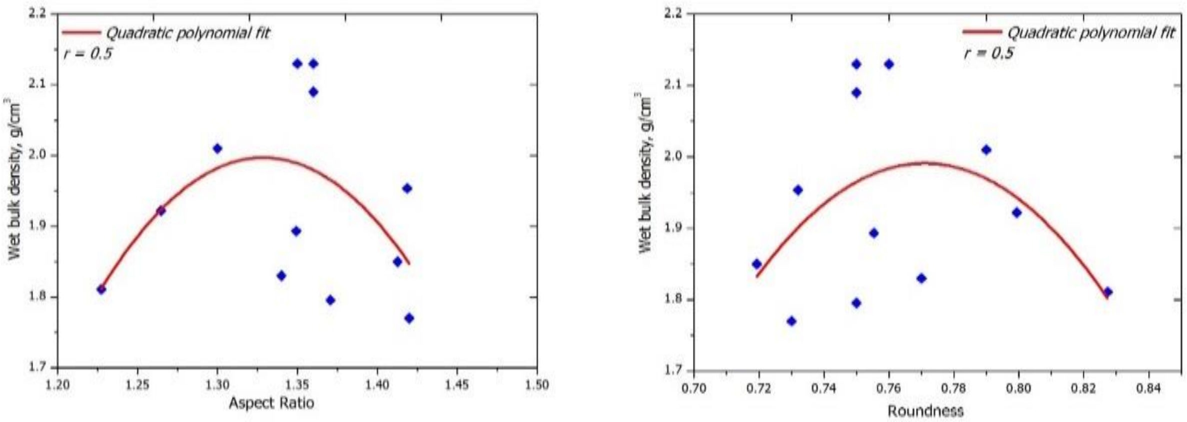
3.3 Relationships between Physical Properties and Shape Factors:

Taking into consideration one of the primary objective of this work, which is to use DIP&A to estimate or predict the physical properties of soil, the shape factors were used as the independent or predictor variable and plotted on the abscissa (x-axis) while the laboratory results used as the dependent or outcome variable and plotted on the ordinate (y-axis). The results obtained from the laboratory tests (TABLE II) were statistically correlated and regressed against the shape factors obtained (TABLE IV). The concept of correlation was used to calculate the correlation coefficient (r), which is the objective measure and premise of the correlation and the regression analysis performed using OriginPro 8 and SPSS software. The output of this regression analysis were relation models that defines the best fit line that represent the relationships between physical properties and shape factors of soil as shown in Figs. 8 to 12 and presented in TABLE V



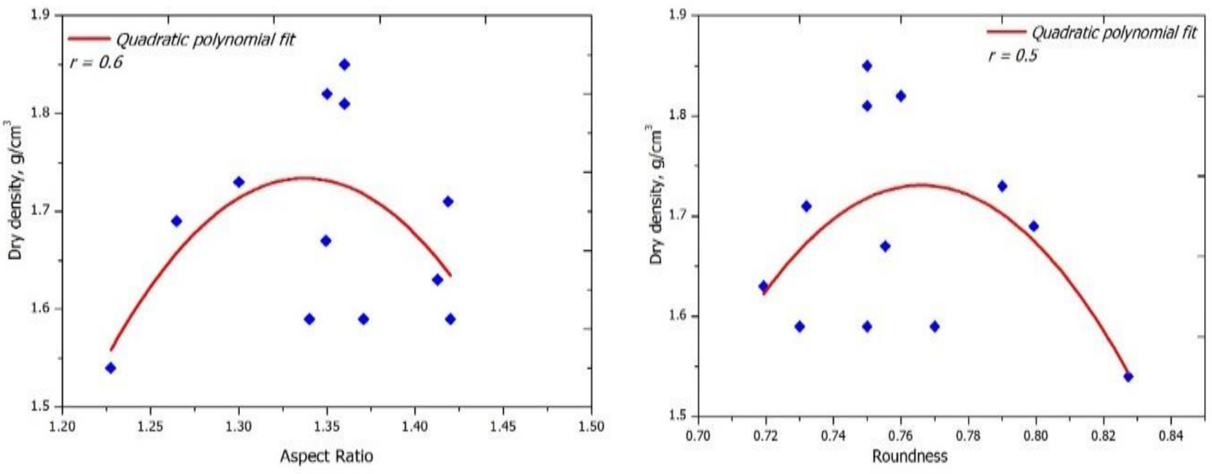
(a) **(b)**

Fig. 8: Relationship between water content and (a) aspect ratio (b) roundness



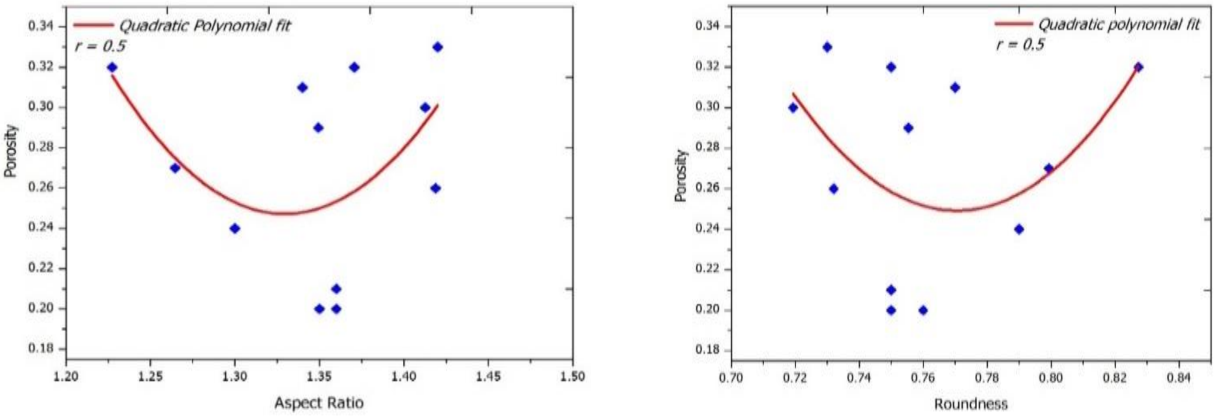
(a) **(b)**

Fig. 9: Relationship between wet bulk density and (a) aspect ratio (b) roundness



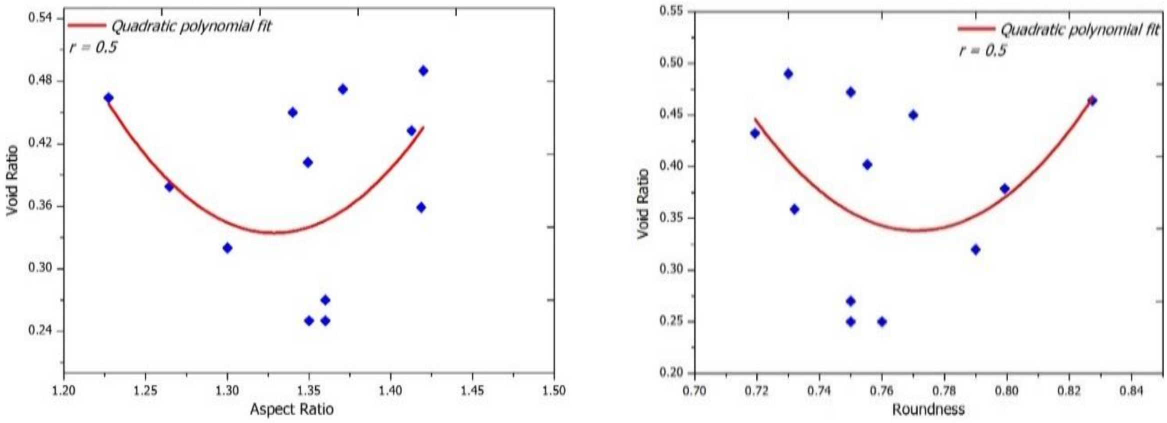
(a) **(b)**

Fig. 10: Relationship between dry density and (a) aspect ratio (b) roundness



(a) **(b)**

Fig. 11: Relationship between porosity and (a) aspect ratio (b) roundness



(a) **(b)**

Fig. 12: Relationship between void ratio and (a) aspect ratio (b) roundness

TABLE VI: THE RELATION MODELS OF PHYSICAL PROPERTIES AND SHAPE FACTORS

y	x	Relation Model	r
Water Content, %	AR	$y = -76.6x^2 + 186.28x - 97.064$	0.6
	Ro	$y = -110.23x^2 + 203.32x - 76.185$	0.6
Wet Bulk Density, g/cm^3	AR	$y = -17.993x^2 + 47.817x - 29.771$	0.5
	Ro	$y = -59.53x^2 + 91.791x - 33.393$	0.5
Dry Density, g/cm^3	AR	$y = -14.536x^2 + 38.879x - 24.263$	0.6
	Ro	$y = -49.831x^2 + 76.344x - 27.51$	0.5
Porosity	AR	$y = 6.5757x^2 - 17.485x + 11.871$	0.5
	Ro	$y = 22.079x^2 - 34.025x + 13.358$	0.5
Void Ratio	AR	$y = 12.1x^2 - 32.151x + 21.692$	0.5
	Ro	$y = 40.348x^2 - 62.218x + 24.324$	0.5

The correlation coefficients (r) ranges from 0.5 to 0.6, indicating that there were relatively strong correlation between physical properties and shape factors of soil and there exist a nonlinear relationship between the variables. The results of the regression analysis further suggest some quadratic polynomial equations that represent the relationship between soil physical properties and its shape factors. Likewise as illustrated in Fig. 13, there exist a very strong (r = 0.98) inverse relationship between the roundness and aspect ratio such that as the roundness of the fragmented soil aggregates increases, the aspect ratio tend to decrease and vice versa, similarly a linear equation was obtained as the relationship between the roundness and aspect ratio as shown in the equation below:

$$Ro = -0.51643AR + 1.45714$$
(7)

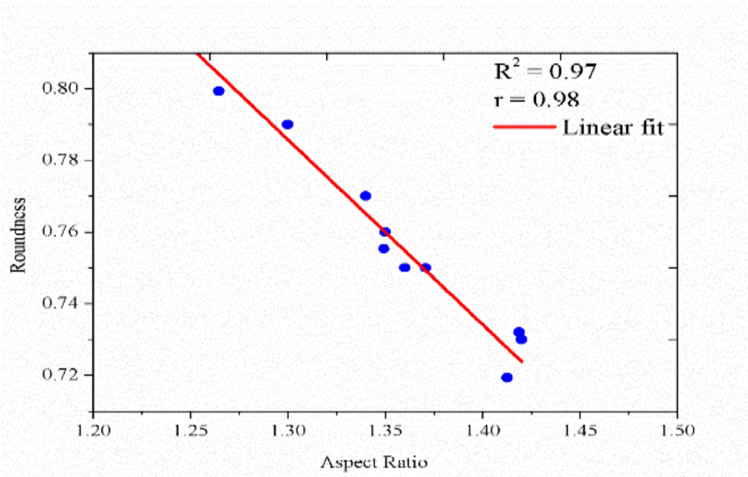


Fig. 13: Relationship between roundness and aspect ratio

3.4 Validation of Results:

To validate the results of the digital image analysis, a sample of soil was collected from a site located about 700m away from the first site used to develop the relation models. All the physical soil properties(y) (TABLE VII) and image capturing, processing, and analysis to determine the shape factors were determined in the same laboratory as outlined in sections 2.1 to 2.5 of this paper. The shape factors(x)-aspect ratio and circularity were found to be 1.39 and 0.74 respectively as shown in TABLE VIII. Replacing these values in the developed relation models with respect to different soil physical properties resulted in a percentage of error ranging from 1.05% to 3.57% as presented in TABLE IX.

TABLE VII: EXPERIMENTAL RESULTS OF VALIDATED SOIL SAMPLE

Physical Properties	Results
Water Content, %	14.27
Wet Bulk Density, g/cm^3	1.91
Dry Density, g/cm^3	1.67
Porosity	0.28
Void Ratio	0.39

TABLE VIII: DIP&A RESULTS – SHAPE FACTORS OF VALIDATED SOIL SAMPLE

Shape Factors	Results
Aspect Ratio	1.39
Roundness	0.74

It should be noted that the values from the laboratory experiments for the validation were used as the true value and the results obtained from replacing the validated results in the relation models used as the observed value in calculating the percent error as presented in equation 8 below:

$$R_E = \left| \frac{T_V - O_V}{T_V} \right| \times 100$$
(8)

Where:

R_E = Relative Error, %

T_V = True Value

O_V = Observed Value

TABLE IX: PERCENT ERROR BETWEEN CONVENTIONAL LABORATORY TESTING AND DIP&A

Physical Properties	Shape Factors	From Laboratory Test	From Image Analysis	Relative Error, %
	AR		13.87	2.80
Water Content, %	Ro	14.27	13.91	2.52
			Average	**2.66**
	AR		1.93	1.05
Wet Bulk Density, g/cm^3	Ro	1.91	1.93	1.05
			Average	**1.05**
	AR		1.69	1.20
Dry Density, g/cm^3	Ro	1.67	1.70	1.80
			Average	**1.50**
	AR		0.27	3.57
Porosity	Ro	0.28	0.27	3.57
			Average	**3.57**
	AR		0.38	2.56
Void Ratio	Ro	0.39	0.38	2.56
			Average	**2.56**

IV. CONCLUSION

Following an experimental and analytical approach on the research parameters, the following conclusions can be drawn based on the discussions presented herein;

- There were relatively strong correlations (r ranges from 0.5 to 0.6) between soil physical properties and the shape factors of its fragmented aggregates.
- The relationships between the physical properties of soil and shape factors were obtained by curvilinear models, suggesting that there are nonlinear relationships between soil physical properties and shape factors. There were quadratic polynomial relationships between soil physical properties and the shape factors of its fragmented aggregates.
- There was a high correlation/relationship (r = 0.98) between the studied shape factors. An inverse linear relationship was found between the roundness and aspect ratio, such that as the roundness of fragmented soil aggregates increases, their aspect ratio tend to decrease and vice versa.
- When the results were validated, the percentage of error between conventional laboratory test and DIP&A resulted in a reasonable percent error ranging from 1.05% to 3.57%.
- The DIP&A method used in the study was shown to be a valuable tool for measuring the geometric properties of soil aggregates.

The principal limitation of the study is the relatively small number of samples collected and tested, but the objective was to establish relationships between soil physical properties and its image feature as indicated in the study. Even though the study found some relationships between soil physical properties and shape factors, from the data collected, it was not possible to determine the effect of these shape factors on the physical properties of soil. Hence, further studies that incorporate more data are therefore necessary to determine the effects of shape factors on the physical properties of soil. Additionally, on the evidence of this study, it appears that DIP&A method proposed in this study should be used to estimate soil physical properties and the relationships found can be reference by geotechnical engineers to understand the preliminary behavior of clayey sand where the geotechnical data are not readily available instead of the conventional laboratory tests which are burdensome and time-consuming. However, it should be pointed out that further studies on the image analysis systems (a computer system to automatically capture the images of soil and both the top and front view of the soil particles be capture to improve the reliability of the results) are needed and the acquisition of soil images be done on site to make more useful and practical method of DIP&A.

ACKNOWLEDGMENT

The authors would like to acknowledge the National Sci-Tech Support Plan (Grant No.2014BAK14B05) and the National Natural Science Foundation (Grant No.51078110) for the financial supports. We appreciate the Key Lab of Structures Dynamic Behavior and Control of the Ministry of Education, P.R. China and the Soil Testing Laboratory and Soil Structure Analysis Centre of Harbin Institute of Technology for allowing us used their facilities. We are also grateful to Mrs. Zhang, the lab technician for her selfless and valuable advices during the soil testing process.

REFERENCES

[1] Brady, N. C. (1974),"The Nature and Properties of Soils", MacMillan, New York, pp.617.

[2] Das, B. M. (2007),"Principles of Geotechnical Engineering", 7th Edition, CENGAGE Learning, USA, pp.1.

[3] Naphade, K.S. (1999),"Soil Characterization Using Digital Image Processing", Thesis for the Degree of Master of Science Degree in Civil Engineering, Lehigh University, USA.

[4] Mardia, K.V., Baczkowski A.J., Feng X., Hainsworth T. 1. (1997),"Statistical Methods for Automatic Interpretation of Digitally Scanned Finger Prints", Pattern Recognition Letters, Vol. 18, 1197-1203.

[5] Russ J.C. (1994),"The Image Processing Handbook", CRC Press.

[6] Macedo, A, Vaz, C.M.P., Nairne, M. et al., (1999),"X-Ray Microtomography to Characterize the Physical Properties of Soil and Particulate Systems", Powder Technology, Vol. 101, 178-182.

[7] Hryciw, R.D., Jung, Y., Susila, E. and Ibrahim, A. (2009),"Thin soil layer detection by VisCPT and FEM simulations", Proc. Int. Conf. Soil Mech. Geotech. Engrg. Alexandria, Egypt 1052-1055.

[8] Lee, C.H., Chiu, Y.C., Wang, T.T. and Huang, T.H. (2013),"Application and validation of simple image-mosaic technology for interpreting cracks on tunnel lining", Tunn. Undergr. Sp. Tech. 34: 61-72.

[9] Zheng, J. and Hryciw, R.D. (2014)," Soil particle size characterization by stereophotography", Proc., GeoCongress 2014.

[10] Suncar, O.E., Rathje, E.M. and Buckley, S.M. (2013),"Deformations of a rapidly moving landslide from high-resolution optical satellite imagery", Proc., GeoCongress 2013, GSP No. 231, 269-278.

[11] Santamarina, J.C., Cho, G.C. (2004)," Soil Behavior: the Role of Particle Shape", Proceedings Skempton Conference, London.

[12] Sezer Alper, Altun Selin, Goktepe Burak Ahmet (2011),"Relationships between Shape Characteristics and Shear Strength of Sand. Journal of Soils and Foundation", Japanese Geotechnical Society, Vol.51, No.5, 857-871.

[13] Rouse, P.C., Fennin, R.J., Shuttle, D.A. (2008),"Influence of Roundness on Void Ratio and Strength of Uniform Sand", Geotechnique 58(3), 227-231.

[14] ASTM D 2937-10, (2010),"Standard Test Method for Density of Soil in Place by Drive-Cylinder Method", American Society for Testing and Materials, West Conshohocken, PA, www.astm.org.

[15] Hvorslev, M.J. (1948). Surface Exploration and Sampling of Soils for Engineering Purposes. *Engineering Foundation*, 345 E. 47th St., New York, NY 10017.

[16] ASTM D 7263-09, (2009)," Standard Test Methods for Laboratory Determination of Density (Unit Weight) of Soil Specimens", American Society for Testing and Materials, West Conshohocken, PA, www.astm.org.

[17] ASTM D 2216-10, (2010),"Standard Test Method for Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass", American Society for Testing and Materials, West Conshohocken, PA, www.astm.org.

[18] Masad, E. and Sivakumar, K. (2004),"Advances in the Characterization and Modeling of Civil Engineering Materials Using Imaging Techniques", Journal of Computing in Civil Engineering, ASCE Editorial, 18:1-1.

[19] Rodriguez, J.M. (2013)," Importance of the Particle Shape on Mechanical Properties of Soil", PhD Dissertation, Lulea University of Technology, Sweden.

[20] Perfect, E., Diaz-Zorita, M., Grove, J.H., (2002),"A Prefractal Model for Predicting Soil Fragment Mass-Size Distributions", Soil Tillage Research, 64(2002), pp. 79-90.

[21] Arasan, S., Yenera, E., Hattatoglu, F., et al., (2011),"Correlation between Shape of Aggregate and Mechanical Properties of Asphalt Concrete", Road Materials and Pavement Design, 12:2, pp. 239-262.

[22] Kuo, C.Y. (1994),"Quantifying the Fabric of Granular Materials: An Image Analysis Approach", PhD Dissertation, Georgia Institute of Technology, Georgia.

[23] Sierra, J. (1982),"Image Analysis and Mathematical Morphology", London, UK: Academic Press. Vol.1.

[24] Janoo, V. (1998),"Quantification of Shape, Angularity and Surface Texture of Base Coarse materials", US Army Corps of Engineers Cold Region Research, Special Report 98-1.

[25] Swiss Standard SN 670 010b, (1999),"Characteristics Coefficients of Soils", Association of Swiss Road and Traffic Engineers.

[26] Zhou Jing and Zhang Xudong (2011),"Fractal Characteristics of Soil Particles in Surface Layer after Vegetation of Small Watershed in Wuling Mountain". IEEE, 978-1-4577-0290-7/11.