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Full Length Article

Cellular-phone-based computer vision system to extract shape properties of coarse aggregate for asphalt mixtures

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ABSTRACT

A new computer-vision cellular-phone-based methodology and scheme was developed to determine the shape properties (Flatness Index, Elongation Index and Roundness Index) of coarse aggregate particles. This scheme utilizes cellular phones images and image processing techniques (IPT) in determining the coarse aggregate particles shape properties. This methodology compared with the conventional methods, which need special laboratory technicians and are time consuming was faster and more accurate procedure. Fifty coarse aggregate particles were collected and their shape properties were measured manually (using caliper and AutoCAD) then computed using image processing procedure. To compute these shape properties using image processing, special data acquisition method was designed and implemented. The aggregate particles were arranged on a grid of an apparatus designed specifically for this task, and mapped by the cellular phone from two views; top view and side view. Then cellular phones images were analyzed with ImageJ software.

1. Introduction

Aggregates are the most important components in flexible pavements, as it has a major role in deformation resistance, and it is used as the main material in the subbase layer. Aggregate contributes in bout 80–95 percent of the bituminous mixture volume. Asphalt concrete performance is highly affected by the aggregate size, shape properties and gradation. Subsequently, the optimum asphalt content is influenced greatly by aggregate characteristics, which in turn affects all other HMA characteristics [1]. Natural crushed aggregate is commonly used in asphalt concrete mixtures. Recently, researchers start looking into using Recycled Aggregate Concrete (RAC) as an alternative aggregate [2,3]. The mutual bonds between coarse aggregate particles and the interaction with the asphalt binder is related directly to the coarse aggregate characteristics (angularity, shape and texture). Aggregate shape properties measurement is crucial in good quality control of the aggregate. In addition, such measurements may help in better understanding of the effect of aggregate characteristics on the pavement structure performance [4].

HMA strength and workability are effected by surface texture of the coarse aggregate. Strength of the HMA is increased with rough surface texture of aggregate, which in turn requires higher asphalt content to provide the proper workability.

In addition, rough aggregate particles produce higher voids in the compacted mixture. Stronger mechanical bond between rough aggregate surface and asphalt binder is produced compared to smooth aggregate surface [5].

Cubical aggregate particles are desired in the Hot Mix Asphalt (HMA) rather than flat and elongated. Cubical aggregate caused strong bonds in the hot mix asphalt, while the flat and elongated aggregate create weak bonds and this cause segregation in the future [6]. Furthermore, Angular shape particles provides better stability for the HMA through the higher internal friction and higher aggregate interlock. Conversely, rounded aggregate particles (such as natural sands and gravels) in HMA produce better workable mixture that needs less compaction effort to obtain the desired density. Microstructure of HMA has great influence on mixture properties. The experimental characterization of the microstructure of the HMA is highly related to the HMA macroscopic behavior. Microstructure distribution influence on the material macroscopic reaction will be better quantified [7].

Flatness Index (FI), Elongation Index (EI), and Roundness Index (RI), are the most aggregate shape properties that affect the aggregate performance in the hot mix asphalt [8]. Rounded particles are expected to have less stability and less particle to particle interlock

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than fractured aggregate particles. ASTM D 4791 [9] specifies that the aggregates, which are not flat nor elongated, will have higher compressive strength than flat or elongated particles of the same material.

2. Aim of the study

This research aims to investigate the image processing potential in accurately determining the shape properties (Flatness Index, Elongation Index, and Roundness Index) of coarse aggregate particles by using cellular phones images and IPT instead of the conventional methods. The conventional method for determination of aggregate shape properties is considered to be time consuming since it requires a series of exhaustive analytical and laboratory steps. The new procedure saves the user's time and gives accurate measurements of the aggregate particle shapes' indices.

3. Literature review

Image processing techniques (IPT) described as performing some operations on images to extract some useful information by process the image through special software like ImageJ software. IPT used to determine the length, width and thickness of particles. These measurements used to determine the flat and elongated particles. On the other hand, cellular Phone image means the image that is captured using the Cellular phone in 2D using normal-based mapping technique.

The use of image processing came from the constraints and limitations that effect on the manual method. These traditional methods need laboratory technicians and lots of time because it is slow testing, and not significant to measure the large amount of coarse aggregate particles [10]. The manual procedure is not effective way to measure the shape indices of large numbers of coarse aggregate. On the other hand, image processing can be used to arrange large number of coarse aggregate (25, 50, 75, 100 or more particles) on the grid then map them using the cellular phone image after this it can be analyzed to get the coarse aggregates' shape properties. Image processing is the process of collecting the information from the image through studying the pixel array. This method has been used in many applications, and one of these applications is the analysis of the coarse aggregate particles images and extract flat and elongated particles ratio [11]. Image processing is done through using a digital camera and advanced lighting technology to capture images with high accuracy. Maerz and Lusher [12] used the two perpendicular cameras fixed above the conveyor belt that contain flat and elongated particles. The images of the particles were taken by two cameras at the same position to measure the dimensions of the flat and elongated particles. Weingart and Prowell [13] used the digital devices such as VDG-40 video grader to measure the gradation of coarse aggregate and to measure the flat and elongated particles. Image processing techniques used to determine the length, width and thickness of particles. These measurements used to calculate the flat and elongated particles. Image processing techniques used to determine the length, width and thickness of particles. These measurements used to calculate the flat and elongated particles. Moaveni et al. [14] evaluated the aggregate size and shape using an innovated field image-acquisition and image-processing techniques by using digital single lens reflex camera. Results indicates that this proposed system can be used to capture several aggregate particles in a single image for rapidly.

Kumara et al. [15] used ImageJ software and an image analysis technique to investigate the gravel size distribution. Results show that, aggregate gradation curve produced by this method is similar to that obtained from sieve analysis. The image analysis method is simple in nature (needs only computer and camera), and it needs short time (compared to sieve analysis).

Arasan et al. [16] investigated the effect of particles size and shape on the aggregate particle size distribution using image processing; ten aggregate samples with variations in properties were treated with image processing using the ImageJ software and proper threshold value. The result showed that the classifications of aggregates according to the automated method and mechanical analysis were almost the same. When image analysis is used in grain size distribution, more accurate results were obtained from front views compared to the top views of the grain particles.

Breytenbach et al. [17] used 3D laser scanning method to study the shape and texture of coarse aggregate (the angularity and roundness). It was found that it is hard to distinguish between particle shape and texture of coarse aggregate particles.

It was proven from the previous research that the image analysis techniques are simple and less time consuming compared to conventional methods. It needs only a computer and camera, therefore, it can be used as in situ method.

4. Methodology

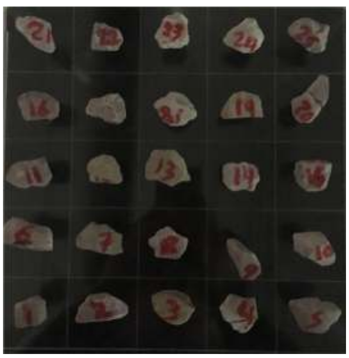
Shape properties of coarse aggregate particles are measured using the image processing approach. Coarse aggregate are defined as aggregates with sizes more than 4.75 mm. In this study, the aggregate sizes of more than 12.5 mm were used. Fifty coarse aggregate particles were collected and their dimensions were defined; twenty-five large size course aggregates retained on sieve No. 1 (25 mm) and twenty-five medium size ones retained on sieve No. 1/2 (12.5 mm). The shape properties (Flatness Index, Elongation Index and Roundness Index) of these aggregate particles were computed using the manual procedure and using image processing procedure and the results from the two procedures were compared to each other.

The manual caliper was used to get the dimensions of the aggregates (length, width, and thickness) then apply the mathematical ratios for Flatness Index and Elongation Index. Roundness Index was computed using AutoCAD Software. To compute these shape properties using Image processing, the aggregates were arranged on a grid and mapped using the cellular phone digital mapping frame for aggregates and from two views (top view and side view), then analyze these images also by ImageJ software. The particles were labeled as shown in Fig. 1a.

The aggregate particle roundness Index was determined by using AutoCAD software. The roundness Index is an indication for the Coarse Aggregate Angularity (the roundness index decreases if the aggregate particle is more flat or elongated). Angularity is important to shape property for the interlock bonds between the aggregate and the binder in the bituminous mixtures. In this study, the cellular phone used to map the aggregate particle from top and side views. A cellular phone with resolution equal to 2448×2448 pixels, and the distance of capturing the aggregate images were 35 cm vertical height for the top view and 35 cm horizontal distance from the side view, see Fig. 1 (a, b and c). These images are taken from the top of the mold that was designed specifically for aggregates mapping. The suitable height for the camera subject distance was 35 cm, which was impossible to map the field of view of aggregates without zooming-in of the camera which gave a resolution 378×391 pixels; i.e. the camera resolution was reduced from 2448×2448 pixels to 378×391 pixels to be compatible with the height of camera to the mapped aggregate.

These views were used to measure the aggregate particle dimensions, which were used in the mathematical equation in order to calculate the aggregate shape parameters (Flatness Index (FI), Elongation Index (EI), and Roundness Index (RI)).

(a) two sizes for the aggregates



(b) top view

(c) side view

Fig. 1. Course aggregate.

FI and EI for the aggregates were determined using the mathematical formulas (1) and (2) below:

$$\textit{Flatness Index}\ (FI) = li/\mathrm{ti} \tag{1}$$

Where:

l_i = length of the particle.
t_i = thickness of the particle.

$$\textit{Elongation Index}\ (EI) = \mathrm{li}/wi \tag{2}$$

Where:

l_i = length of the particle.
w_i = width of the particle.

The length, width and thickness of the aggregates particle were measured using a manual caliper. In this experiment the AutoCAD software was used to get the minor perimeters as the user keep tracking the aggregate perimeter and draw circles (n). The mathematical formula (3) was used to compute the Roundness Index:

$$\textit{Roundness Index}\ (RI) = \left(\sum_{i=1}^{n} \frac{ri}{R}\right)/n \tag{3}$$

Where:

R = radius of the major centered circle.
ri = the radius for the minor perimeters' circles as it is shown in Fig. 2.

The roundness index was computed for the coarse aggregates from the top view as shown in Fig. 3a and from the side view as shown in Fig. 3b. Cellular phone was used to capture images for

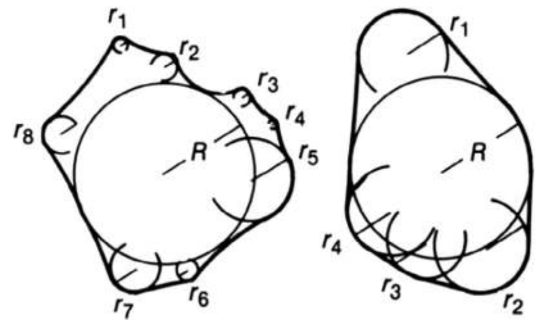


Fig. 2. Radii for the roundness.

the aggregate particles. Then these images were imported to the AutoCAD software where it was used to measure the radii for the major and the minor perimeters of the aggregate particles. The roundness index was calculated using mathematical formula (3) for every single particle. It is worthy to mention that, AutoCAD results were verified using some real direct measurements such as caliper. The caliper was used to get real measurement for the aggregate particles for some regular and irregular shapes and results were found to be very close.

The proposed methodology is unique in its nature where it depends on using cellular phones images and Image Processing Techniques (IPT). Cell phones have the advantage of availability, hand-held, following up technological trend, high resolution cameras, flexibility of field of view and worldwide spreading.

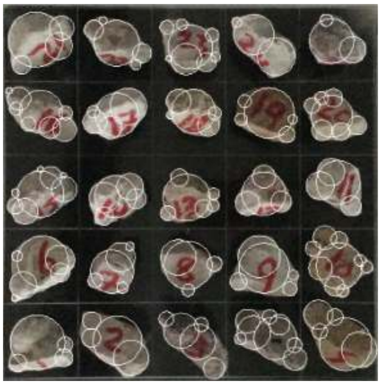
5. Shape properties of coarse aggregate particles calculations

Fig. 4a and b show a sample calculation of elongation index and flatness index for one of the aggregate particles, where the length, width and the thickness of the aggregate particle are used. A sample calculation for calculating the top and side roundness for aggregate particle labeled with number 1 is shown in Fig. 5 where different radii values are needed.

Mainly, this study aims to eliminate the laboratory work and to save the time and the effort of finding the aggregates shape properties. A special apparatus frame for the data collection was designed using AutoCAD software as shown in Fig. 6. Then it was implemented for capturing cellular phone images for a sample of aggregates. This frame consisted of two plates and four ruler columns. All the components were made of reinforced plastic and four stainless steel footings.

As shown in Fig. 7, the upper plate has square shape (30 cm × 30 cm) with middle opening for the cellular phone camera, the plate can be fixed on any height by using the rulers on the columns and the stoppers under the plate, the plate should be level to get vertical top view in the aggregates. At the bottom, there is a plate with a square shape (40 cm × 40 cm) and it is 4 cm thickness. There are two thin plates working as drawers, the upper thin plate is transparent and there is a grid (25 cm × 25 cm) on it. This grid was prepared by laser machine 25 squares; each square is 5 cm × 5 cm. The color of the lower thin plate is black. Twenty-five aggregate particles were arranged on the grid. The use of this grade is to get the scale and to keep the aggregate arranged with known distances. When the aggregates were arranged on the grid, the thin plate can be removed and replaced by the black one.

After different experimental trails, the heights of capturing the image less than 30 cm will be very close so not all the aggregate particles in the sample will appear in the photo. On the other hand, heights more than 40 cm will result in unclear image. As result, 35 cm was selected as average height to map the aggregate sample,



(a) top

(b) side

Fig. 3. Coarse aggregate Roundness Index (RI).

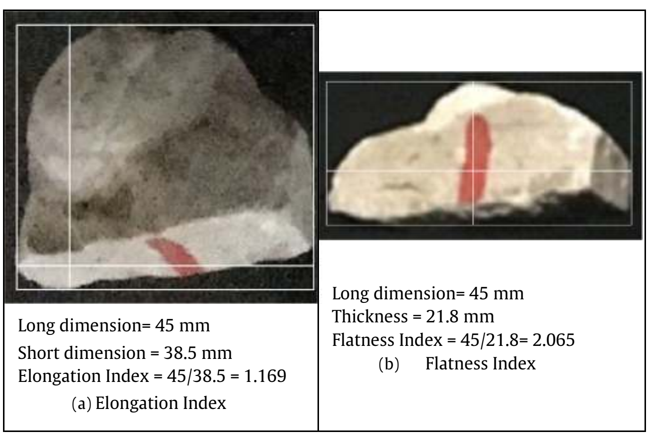


Fig. 4. Sample calculation of elongation and flatness indices.

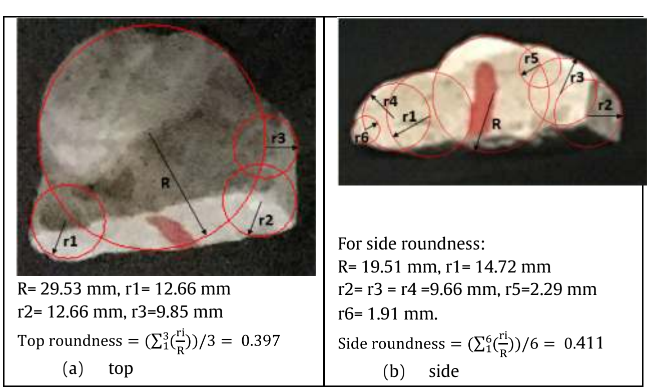


Fig. 5. Sample calculation of roundness index.

where the user can track the aggregate perimeter and the feature lines of the aggregate will be clear (compared to the 40 cm height). A test was performed by different users to capture the aggregate sample, most of the uses fixed the cellular phones at a height around 35 cm. So the suitable height for mapping the aggregate by the cellular phone camera was 35 cm. Two images were taken by high-resolution cellular phone's camera for the aggregates samples that were arranged on the plate according to the lower grid plate. Two sizes of coarse aggregates were selected and arranged using the frame as shown in Fig. 8.

Image processing techniques components consists of (i.e. steps before ImageJ analysis):

1. Arrange the aggregate particles on the grid (large and medium sizes were used).
2. Fix the cellular phone using the upper plate in the frame at 35 cm height from the grid.
3. Capture the image of the aggregate particles using the cellular phone.
4. Import the cellular phone image into the computer.
5. Analyze the image using the ImageJ software.

Fig. 9 shows the image processing Technique components with the new data acquisition system and ImageJ software (the flow of steps of image processing is from left to right on the Fig. 9).

6. ImageJ software

The ImageJ software was developed by National Institutes of Health (NIH) Image for Macintosh as a public domain Java image processing program. It is open source (shareware software) and available commercially. There are other software which are used for image processing purpose such as Raw image processing software, Computer vision software, Amira, AVISO, and MATLAB. But most of them are not open sources and not available commercially and/or it needs codes. A virtual machine of Java 1.4 or later is needed to run the ImageJ software. Images of 8-bit, 16-bit and 32-bit can be saved, displayed, edited, printed, analyzed and processed in this program [18].

Distances and angles can be measured using the ImageJ program. Plots of line profiles and density histograms can be created also. The program has the functions of sharpening, smoothing, edge detection, contrast manipulation ad median filtering. Any magnification factor can be used then the analysis can be done accordingly. Furthermore, flips, scaling and rotation is provided.

The ImageJ software supports any number of images at the same time based on the available memory. Measurements in units such as millimeters are used for spatial calibration. Calibration through gray scale of density can be done also [18]. The ImageJ processing program was used for analyzing 2D images (this study shows the potential of using 2D images to extract the aggregate shape properties). The used mapping technique is called the Normal-based image, where the optical axe is perpendicular to the mapped object that guaranteed a constant scale for all pixels in the 2D image. In fact, a nominal scale factor was used in order to measure object distances.

This software is used mainly for biological tasks such as cells detection, but it was used in this study for analysis for coarse aggregate shape properties.

The intensity gradation consists of 256 (28) intensity graduations was assigned as a pixel. Black color is represented as a pixel with zero intensity. On the other hand, white color is represented as a pixel with 255 intensity. Then all colors between black and white represented as a gray shade.

ImageJ was calibrated through comparing the aggregate shape properties obtained through the manual procedure (AutoCAD and the Caliper) with the ones obtained from the ImageJ software (with the suitable threshold value). The threshold value was changed manually to get the suitable threshold value for ImageJ analysis. It was noticed that the threshold value below 30 didn't show clear detectable particle areas, as well as the values more than 50. The

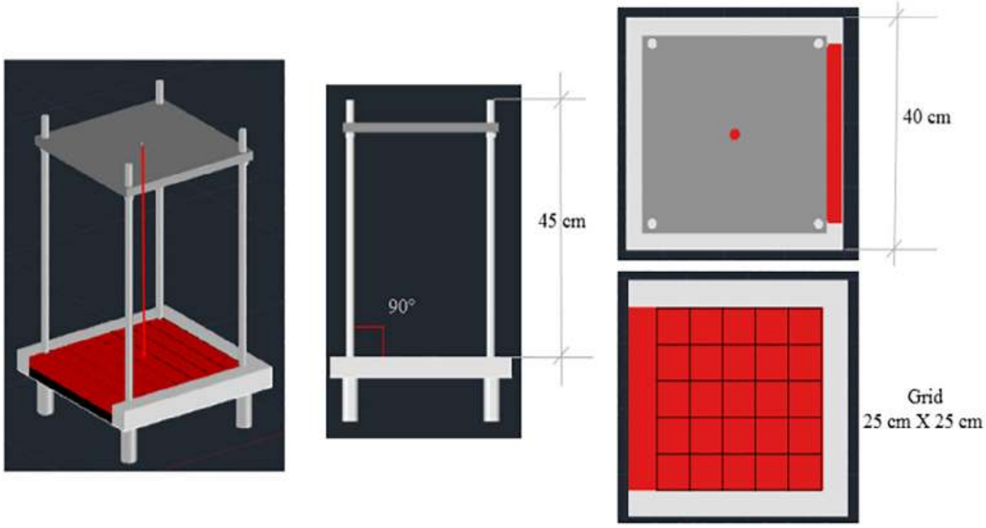


Fig. 6. AutoCAD Design of cellular phone mapping frame for Coarse Aggregates.

Fig. 7. Cellular phone digital mapping frame for coarse aggregate digital mapping mold for aggregate after implementation.

(a) large particles retained on sieve #1 b) medium particles retained on sieve #1/2

Fig. 8. Two coarse aggregate sizes.

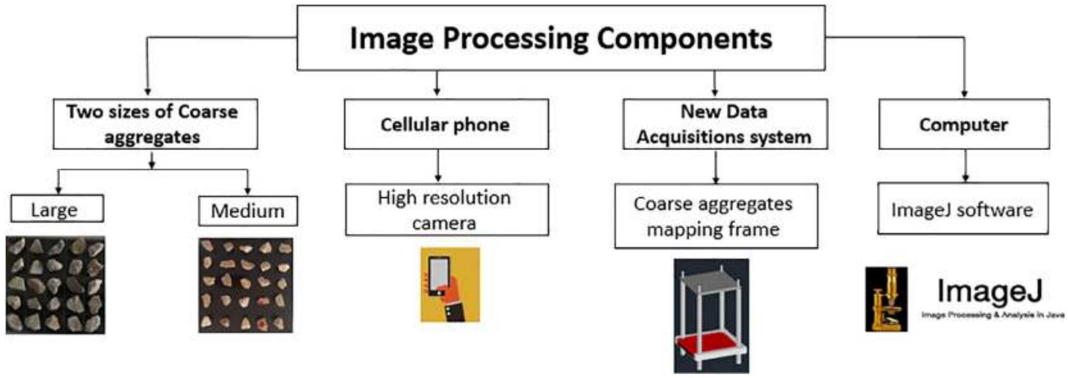


Fig. 9. Image Processing Techniques components.

threshold value was changed manually in this range in order to get the clearest area detection for the aggregate particles and 40 was the value that show the clearest detection for the coarse aggregate particles as shown in Fig. 10. A rigorous calibration procedure was performed to assure the accuracy of extracted images through ImageJ program. The result of calibration gave validation and accuracy

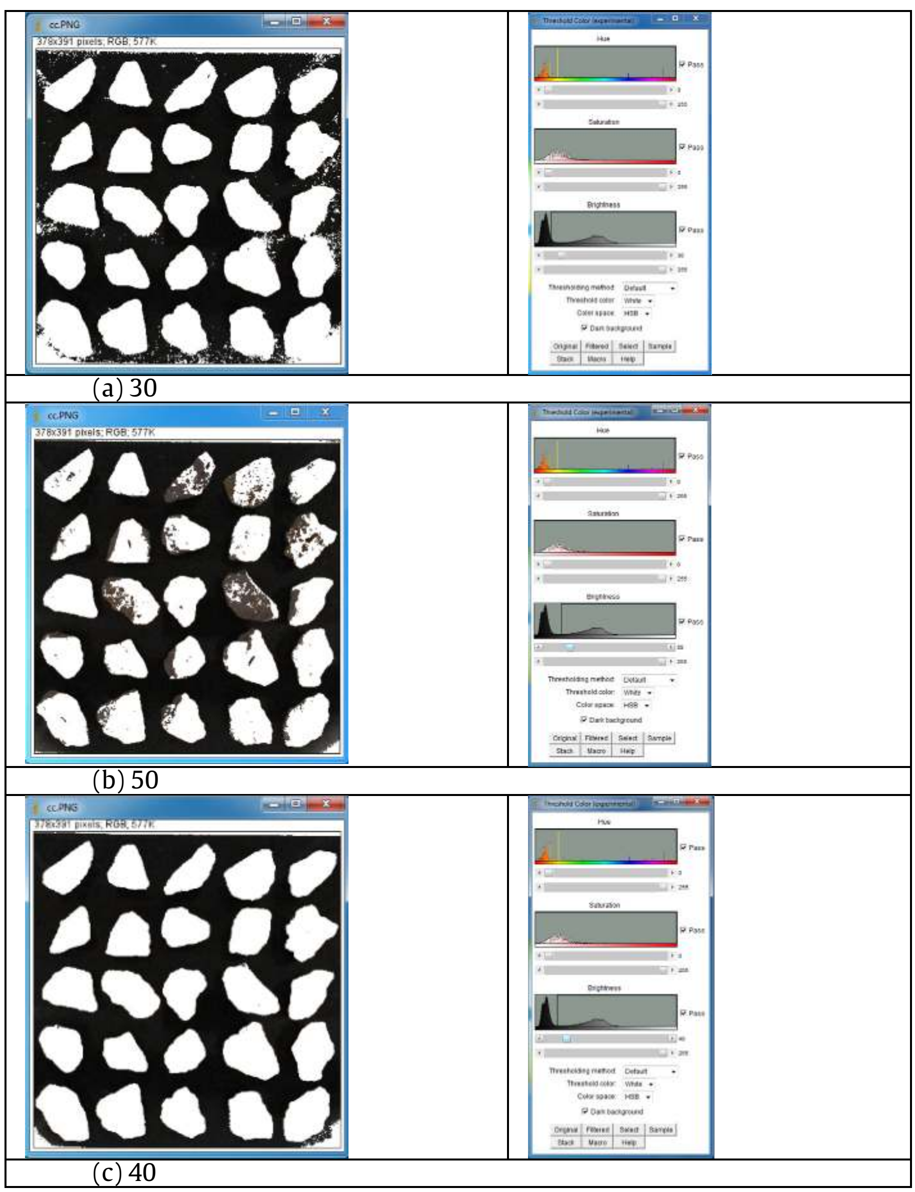


Fig. 10. ImageJ threshold value calibration, analysis for large aggregate top view image using threshold value.

above 97% when compared to manual measurements. The best captured images were taken from a height of 35 cm, where the best resolution was given [19,20].

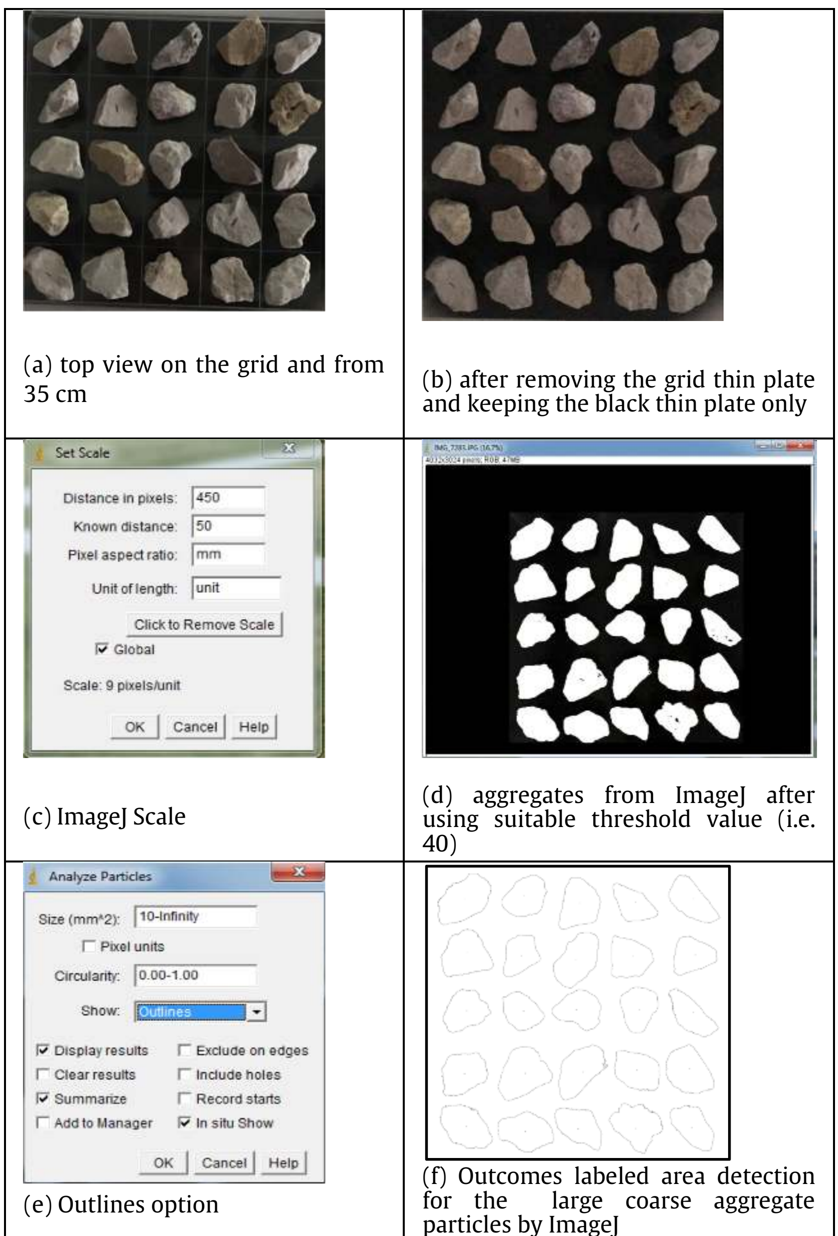
After calibration of the ImageJ software and selecting the suitable threshold value, the aggregate samples top view and side view images went through ImageJ analysis procedure as follows (Fig. 11):

a. Remove the grid thin plate and keeping the black thin plate only under the aggregate.
b. Take a top view image for the mapped aggregate particles that arranged on the grid.
c. Drag and drop the image in the ImageJ software.
d. Adjust the ImageJ Scale.
e. Adjust the threshold value to the suitable one (i.e. 40).
f. Select the outlines option to get the data analysis for the aggregate.
g. Outcomes labeled area detection for the large coarse aggregate particles by ImageJ.

The same procedure was done for the side view for five large coarse aggregate particles. Each five aggregates were arranged on the grid on the first line and cellular phone is fixed at 15 cm away from the edge of the lower plate, after the next four lines of the grid (20 cm), so the distance will be 35 cm. Back background was used, using the black shelf in the same frame, which was under the aggregates in the top view procedure (Fig. 12). Finally, the data from ImageJ analysis was collected and compared to the values computed by the manual procedure.

7. Results and discussion

This section shows the results of coarse aggregates statistical analysis and mainly a comparison between the manual method



(a) top view on the grid and from 35 cm

(b) after removing the grid thin plate and keeping the black thin plate only

(c) ImageJ Scale

(d) aggregates from ImageJ after using suitable threshold value (i.e. 40)

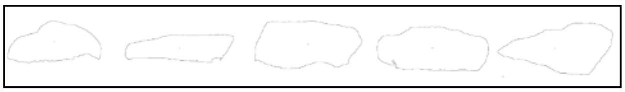
(e) Outlines option

(f) Outcomes labeled area detection for the large coarse aggregate particles by ImageJ

Fig. 11. The ImageJ analysis steps for the large size of coarse aggregate.

(a) first five large aggregate

(b) ImageJ analysis



(c) Outcomes labeled area detection for the side view of 5 large aggregat particles by ImageJ

Fig. 12. ImageJ analysis for the side view of coarse aggregates.

results and the ImageJ software results. Fig. 13 presents that this new system has high potential to bridge the gap between conventional or manual procedures and fully automated calculation methods to find the aggregates shapes parameters such as the roundness, flatness, and elongations indices.

The top roundness of the coarse aggregate particles which were obtained from AutoCAD and from the ImageJ software are plotted in equality line as shown in Fig. 13 a. It is clear from the Fig. 13 a that all points are in line of equality, with linear relation ($R^2 = 0.97$). In other words the ImageJ results are very close to the manual one (using the AutoCAD).

Fig. 13 b shows the side roundness of the coarse aggregate particles obtained from AutoCAD and the side roundness obtained from ImageJ software. As shown in Fig. 13 b all points are in line of equality, with linear relation ($R^2 = 0.98$). This means that the ImageJ software can calculate the roundness Index of the coarse aggregate accurately.

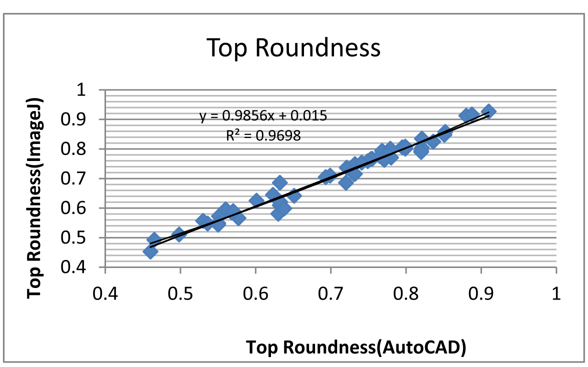
The flatness index of the coarse aggregate particles which were obtained from AutoCAD and from the ImageJ software are plotted in equality line as shown in Fig. 13 c. It is clear from the Fig. 13 c that all points are in line of equality, with linear relation ($R^2 = 0.89$). In other words the ImageJ software results are very close to the manual one (using the AutoCAD).The elongation index of the coarse aggregate particles which were obtained from AutoCAD and from the ImageJ software are plotted in equality line as shown in Fig. 13 d. As shown in Fig. 13 d all points are in line of equality, with linear relation ($R^2 = 0.97$). This means that the ImageJ can calculate the roundness Index of the coarse aggregate correctly.

It is noted that both the elongation index and the roundness index are very similar (0.98 and 0.97 respectively) and the flatness index has the lowest value (0.89) compared to the other indices. May be this low coefficient of correlation of the flatness index is due to the variability in measuring the thickness of the aggregate particles, where the thickness can be measured from different directions due to irregular shape of the aggregate particles.

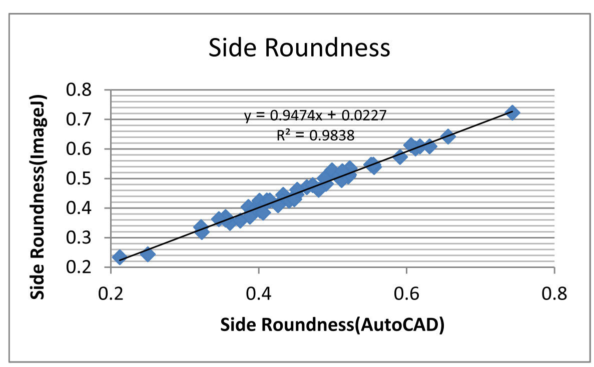
Table 1 shows that there are slight differences between the values of aggregate shape properties (RI, FI and EI) from the manual

Table 1
Summary of errors percentages of the aggregate shape properties indices using Image Processing Techniques using the ImageJ procedure compared to manual method (AutoCAD and Caliper) method.

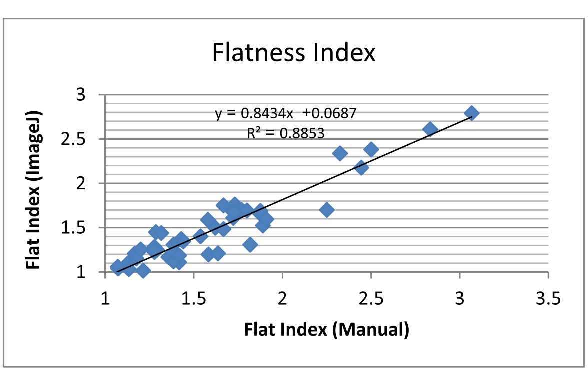
Parameter	RI (top)	RI (side)	EI	FI
Min	0.18	0.00	0.47	0.50
Max	8.53	8.49	9.00	9.46
Average	2.66	2.84	4.76	4.93



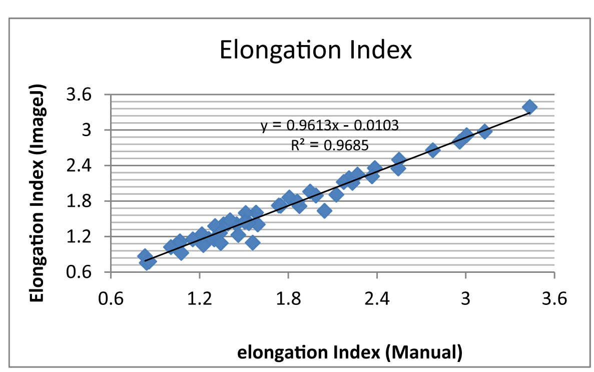
(a) top Roundness Index



(b) side Roundness Index

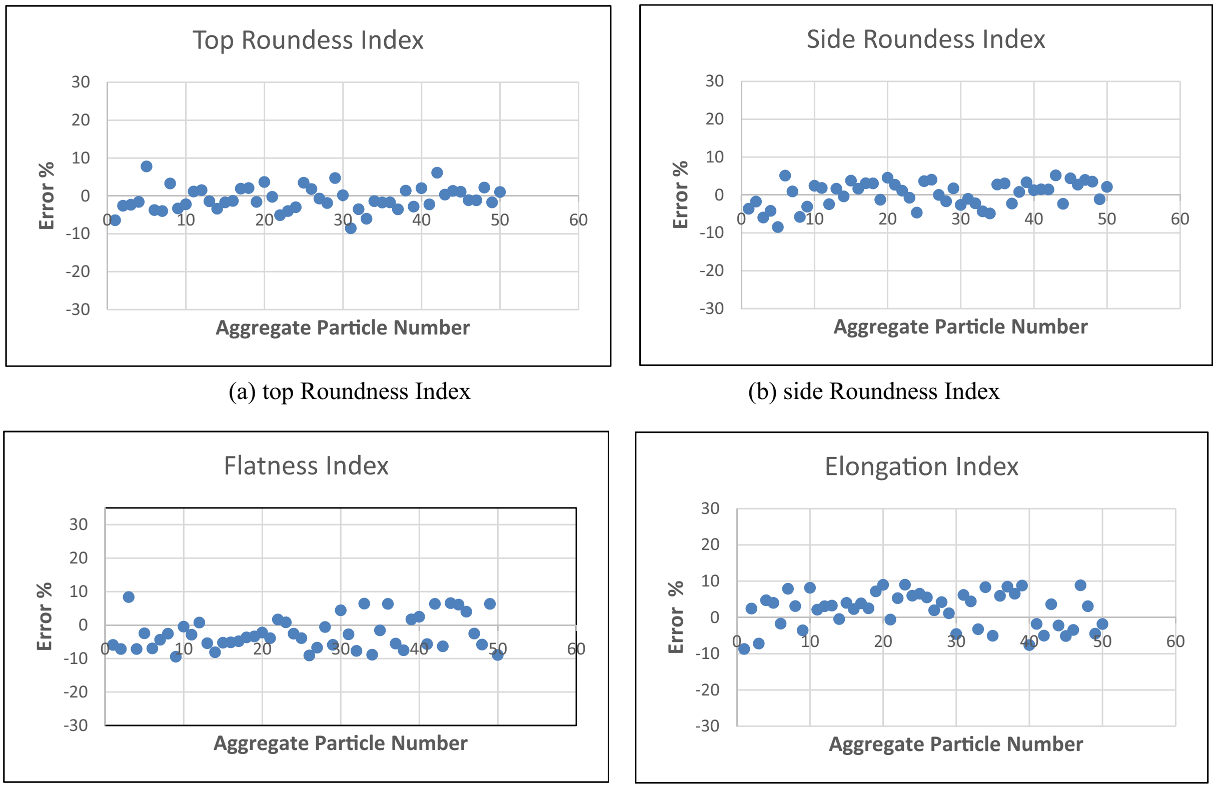


(c) Flatness Index



(d) Elongation Index

Fig. 13. Relationships between the coarse aggregate shape properties from AutoCAD (and caliper) and from ImageJ.



(a) top Roundness Index (b) side Roundness Index

(c) Flatness Index (d) Elongation Index

Fig. 14. Error percentages between Manual Method and the Image Processing Techniques using the ImageJ method for all aggregate particles.

procedure and the values from ImageJ analysis. This table shows the summary of the results in term of differences and error percentages (minimum, maximum and average values). As shown in Table 1 average errors values are very low. The average error (percent) for the top and side roundness is less than 3%. On the other hand, average error (percent) for the flatness index and elongation index is less than 5%. This mean that using the ImageJ software procedure to get the coarse aggregate shape properties is accurate and fast method.

Fig. 14 shows the error for different aggregate indices computed from the manual method (AutoCAD and Caliper) and image processing techniques using the ImageJ. Error percentages for the top and side roundness in general are less than 9% while error values mainly less than 10% for the Flatness and Elongation Indices.

This technique is expected to have high impact to the profession, where it will help in the quality control of aggregate used in the construction of asphalt mixtures. Sine it is easy, fast and does not need any expensive equipment, lab work or technicians. The latest design methods of asphalt mixtures (i.e. Superpave) limits specific percentages of flat and elongated particles, this technique will be very helpful to achieve this goal in a fast and accurate way.

In fact this methodology is novel and unique. Other researches tried to determine the aggregate shape properties manually (that is time consuming and needs lab work), or using expensive devices such CT scan or laser machine to get 3D images for the aggregates [21,22]. Thus, this study, which consider the first of its kind uses 2D images for the aggregates by cellular phones and special frame, shows the potential of using 2D images to extract the aggregate shape properties.

Results of this study can be compared with CT scan or the 3D studies. As shown in Table 1 above, using this technique the maximum error is less than 5 percent (also see Figs. 13 and 14), given the ease of this method with availability and relatively low cost of the equipment needed, this method will be chosen as best option for determining aggregate shape properties.

It is worth mentioning here that the IPT method used in this research work utilized 2D image domain analysis using Normal-Based imaging technique of one cellular-phone camera that guaranteed constant scale in 2D. This technique has the limitation of measuring longitudinal and area-based shape properties such as: Roundness Index, Flatness Index, and Elongation Index; unlike stereo-vision and convergent mapping technique that permits 3D mapping and volumetric surface measurements such as Sphericity. Therefore, Sphericity was out of the scope of this research work.

8. Conclusions

In this study, limestone coarse aggregate shape properties with particle size more than 12.5 mm were quantified by three indices: Roundness Index, Flatness Index, and Elongation Index. These indices were determined by using a computer-vision Cellular Phone Images and ImageJ software image analysis and the manual procedures.

Based on the analysis of data and results of this study, the following conclusions are reached:

1. Cellular Phone Images and ImageJ software were used successfully to calculate the shape properties of coarse aggregates (Roundness Index, Flatness Index, and Elongation Index).
2. The Roundness Index, Flatness Index, and Elongation Index values calculated using both; the IPT and ImageJ software and the manual methods (caliper and AutoCAD) were very close (average error values less than 1.0 percent).
3. The usage of cellular phones and image processing techniques can quantify coarse aggregates shape characteristics accurately.

Result of this research led to the conclusion that there is a highly potential of using cellular phone image and image processing technique for compute the coarse aggregate shape indices. This may open the door for numerous macro and micro mensuration and analysis in the fields of bituminous mixtures, traffic engineering, transportation engineering, and other Civil Engineering applications.

The potential can most fully be exploited if further research is directed to the following recommendations:

1. One type of aggregate (limestone) was used, it is recommended to study other types of aggregate such as basalt.
2. Fine aggregate characterization by image processing were not discussed in this research, further research is recommended for discovering the potential of cellular phone images and image processing to find the fine aggregate properties.
3. Further research is recommended for determination the aggregates gradation used in the mixtures by using cellular phone images and image processing to determine the percentage of the passing through or retained aggregates on each sieve according to the sieve size.

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