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Calculation of Body Mass Index using Image Processing Techniques

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Abstract – **Body Mass Index (BMI) is a number calculated from a person's weight and height. BMI provides a reliable indicator of body fatness which in turn is used to screen for weight categories that may lead to health problems. The conventional way of computing BMI is time consuming and most often results in inaccuracies. This paper presents image processing techniques as an alternative approach to effectively determine body mass index of human beings. The proposed approach captures the image of a person and then converts it into a silhouette. The height and volume is determined using silhouette analysis. The volume and height serve as input parameters to calculate the BMI of a person. The results obtained compare favourably with the results of the traditional way of computing BMI**.

Keywords – **BMI, Images Processing Technique, Pixel, Silhouette.**

I. Introduction

The body mass index (BMI) is a statistical measurement derived from a person's height and weight [1]. The BMI provides a reliable indicator of body fatness for most people and is used to screen for weight categories that may lead to health problems. Today, BMI is considered to be a useful way to estimate healthy body weight in the communities. Such physical measurement is used to assess an individual's total amount of body fat [2]. It must be emphasized that these measurements track weight status in populations and as well as identify potential weight problems in individuals. BMI is an important indicator of overweight and obesity in people.

Consequently, accurate measurements of BMI require that adequate attention be given to data collection and management. BMI data continues to provide extremely important information regarding the rate of acceleration of the overweight and obesity endemic in a community. More so, the data provides a range of scale for 'normal' weight measurement which allows classification and compensation of different body types and shapes in the community.

II. Problem Statement

Despite using BMI as one of the best methods for population assessment of overweight and obesity, it is cumbersome and a time consuming process. The conventional calculation of the BMI results in inaccuracies. This is detrimental in deciding the fitness of an individual. As a result it has become imperative to have efficient solution to make the BMI process fast and error-free.

Silhouette analysis provides quick and inexpensive way to calculate BMI by clinicians and the general public.

III. Related Review

The BMI (Body Mass Index) is an interpretable number obtained when you divide the weight of a person by the square of his/her height. After the initial work in [3] Keys renamed the Quetelet index as body mass index. Though his work does not actually measure the percentage of body fat, it is used to estimate a healthy body weight based on a person's height. The work in [4] used waist circumference to explain obesity related health risk. However in [5] Shrikant preferred a different and fast method of obtaining the height and weight of applicants to the conventional way as proposed in [5]. To him, the conventional way is cumbersome and a time consuming process. Other formulas such as Body Adiposity Index (BAI), hydrostatic weighing among many others were also used to describe the fat content of man. A recent study by Shrikant (2013) on the use of silhouette to calculate BMI emphasized on the use of image processing techniques.

IV. Methodology

Population and Sampling

The research was done using fifty persons from Asorkwa a vibrant Community which is situated behind the Kumasi Stadium in the Ashanti Region of Ghana. The participants used were purposively selected.

Research Instruments

The main instruments used include: digital weighing machine, a five-metre (5m) measuring tape, Samsung High Definition (HD) 16.1 megapixels camera.

Design Methodology

BMI as a ratio which can be very critical in the determination of various heart related diseases is conventionally calculated as:

BMI= Mass / (H*H)

Mass is how much substance is in an object. On Earth, the mass of an object and the weight of an object are identical. Thus, the mass of an astronaut is the same in space as it is on Earth. We expressed mass as

$$\text{Mass} = \text{Density} \times \text{Volume} \quad (1)$$

Using the concept that the human body is made up of about 75% of water, we can assume that the density of a human body will be almost like that of water. Using relative density of water to be $1m/cm^3$ we estimate the mass of an individual if the volume is known as

$$\text{Mass} = 1.0 * \text{Volume} \quad (2)$$

$$\text{Mass} = 1.0 \times (\text{Area} \times \text{Height})$$

Mass is directly proportional to the Area a body covers.

Our image processing technique focuses on only a 2D image, which means that only the area of the body could be determined. Leaving the Height to be constant we conclude on this formula:

Mass = Area.

Our initial attempt to calculate the area of the individual tried to actually determine the area per metre squared (m^2), which involved knowing the object distance from camera, image area, and image distance. The idea meant that any time the body changes distance, the algorithm will have to be modified to match the new distance. A much more simple method is therefore proposed.

Area = Total number of pixels with value equal 1;

The assumption was supported by the fact that BMI is simply a ratio of Mass/H*H. Using a black and white image the area was calculated as:

$$\text{Area} = \begin{cases} 1 & \sum_{1<j<n}^{1<i<m} Imj(i,j) \; \forall Imj(i,j) = 1 \\ 0 & \end{cases}$$

Algorithm
Start
Area = 0
for i = 1 to image_width
for j = 1 to image_height
if Img(i,j) = 1 then
Area ← Area + 1
End
H as height
*BMI = Area / (H * H)*

Proof of Position

The first experiment performed was to prove if indeed the object distance from the camera can adversely influence the formula to be used in the determination of BMI. The experiment was primarily aimed at trying to prove that a general formula can be used on almost all images irrespective of their position. The idea was to come out with a formula that does not restrict the location of a body before the actual BMI could be determined.

Study Design

A sample silhouette was used in this experiment. An image of size 1024 x 768 with an aspect ratio of 4:3 was used to generate nine (9) other images. Each image was 10% smaller than its previous one in the sequence. Three (3) different sequences of 10 images each were subjected to the algorithm already stated.

Explanation of the Formula used

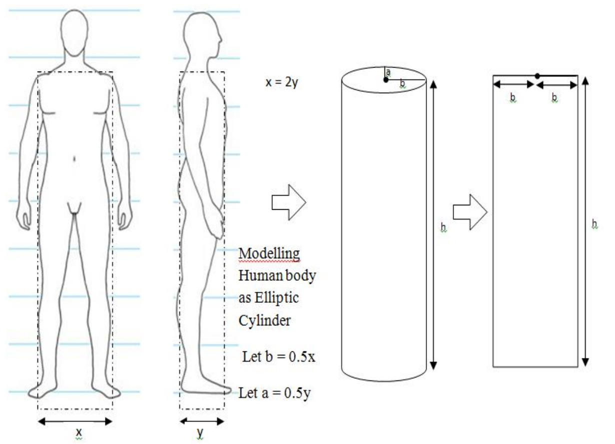

Fig.1. Determination of formula used

From figure 1,

$$Volume = \pi abh$$

$$b = 2a$$

$$a = \frac{1}{2}b$$

$$Cross\ Sectional\ Area = (b + b)h = 2bh$$

$$b = \frac{A}{2h}$$

$$a = \frac{A}{2h} * \frac{1}{2} = \frac{A}{4h}$$

$$\mathbf{Volume} = \pi abh = \pi\left(\frac{A}{2h}\right)\left(\frac{A}{4h}\right)h$$

$$\mathbf{Volume} = \pi\left(\frac{A^2}{8h}\right)$$

$$\textbf{From the above } {}_{ImgBMI} = \frac{\mathbf{VOLUME}}{\mathbf{8H}}$$

The $I_{(BMI)}$ was calculated using the formula:

$$\frac{\pi * A^2}{8 * H^3}$$

Where:

i) Π = 22/7
ii) A = Area occupied by the silhouette in terms of the number of pixels
iii) Image H^3 = Silhouette height (the distance between the highest and lowest pixels of the silhouette)

$$\text{Computed BMI} = \left(\frac{\pi * A^2}{8 * H^3} - 4.1219\right) / 0.1963$$

Table 1: Reduction Table

Image Manipulation	Height	Width
	Vary by 10%	Vary by 10%
	Constant	Vary by 10%
	Vary by 10%	Constant

The results obtained from the first row of table 1 is shown on fig. 2 (i.e. varying both the height and width by 10%).

Fig. 2: Silhouette Reduction by 10%

International Journal of Artificial Intelligence and Mechatronics
Volume 4, Issue 1, ISSN 2320 – 5121

Table 2: shows image size used

Image Size	Height	Width	Reduce 10%	Body Height	Body Area	BMI
1024 x 768	768	1024	1	390	31477	0.207
922 x 691	691	922	0.9	353	26275	0.211
829 x 622	614	819	0.8	313	20752	0.212
746 x 560	538	717	0.7	275	16040	0.212
672 x 504	461	614	0.6	235	11531	0.209
605 x 453	384	512	0.5	196	7925	0.206
544 x 408	307	410	0.4	156	5244	0.215
490 x 367	230	307	0.3	118	3099	0.223
441 x 331	154	205	0.2	80	1443	0.225
397 x 298	77	102	0.1	40	392	0.245

Mean value of the calculated BMIs
Mean = 0.217; Deviation = 0.011823797

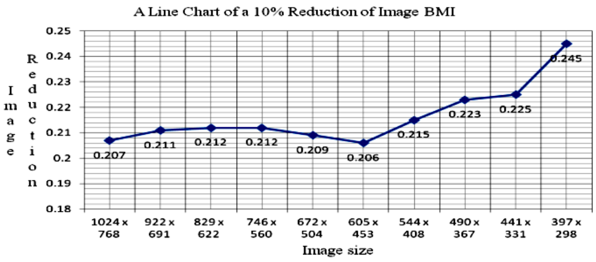

Fig.3. Reduction Line Chart

Table 2 shows the ten percent image size reduction and the corresponding line chart shown in figure 3. The mean value and the deviation of the reduction are also shown beneath table 2 clearly.

Table 3: Image Size and BMI

Image Size	BMI
1024 x 768	0.21
922 x 691	021
829 x 622	0.21
746 x 560	0.21
672 x 504	0.21
605 x 453	0.21
544 x 408	0.22
490 x 367	0.22
441 x 331	0.23
397 x 298	0.25

From table 3, with majority of image giving 0.21 BMI values for about 6 different images sizes and the rest having 0.23 as average suggest that, as the object distance increase beyond a certain limit, the BMI for a particular body may differ, though the value may not be significant.

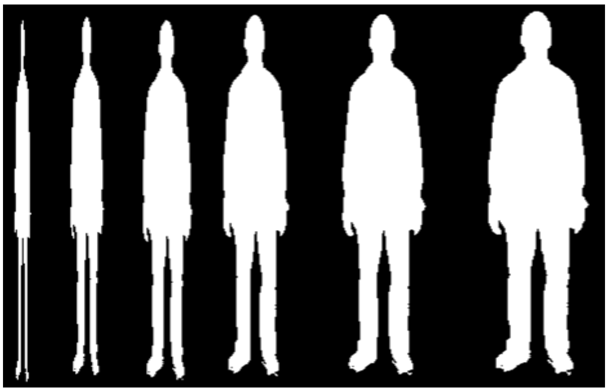
Fig.4. Reduction of Width with Constant Height

The same image was again subjected to compression of the width leaving the height constant as shown in fig. 4. Nine (9) images were generated from the original. On table 4, the same algorithm was applied on the images and a new set of BMI was produced.

Table 4: Reducing Width with Height Permanent

Image	Height	Width	Reduction 10%	Body Height	Body Area	BMI
1.0	768	1024	768 x 1024	390	31477	0.207
0.9	768	922	768 x 922	390	28355	0.186
0.8	768	819	768 x 819	390	25030	0.165
0.7	768	717	768 x 717	390	21913	0.144
0.6	768	614	768 x 614	390	18753	0.123
0.5	768	512	768 x 512	389	15467	0.102
0.4	768	410	768 x 410	389	12255	0.081
0.3	768	307	768 x 307	388	9137	0.061
0.2	768	205	768 x 205	386	5928	0.040
0.1	768	102	768 x 102	385	2646	0.018

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Table 5: Summary of Image Reduction (constant height and 10% reduction width) and BMI

Image	BMI
768 x 1024	0.206949375
768 x922	0.186423406
768 x 819	0.164562788
768 x 717	0.144069691
768 x 614	0.123293886
768 x 512	0.102213176
768 x 410	0.080986776
768 x 307	0.060693219
768 x 205	0.039786303
768 x 102	0.01785124

Table 5 is carved out of table 4 with only the reduced image sizes and the corresponding image processing BMI values.

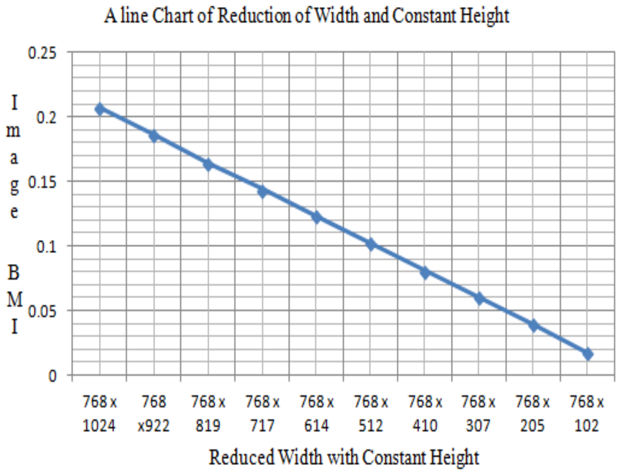

Fig.5. A chart of the Reduced Width

Fig.6. Height Reduction with Constant Width

The same image was again subjected to compression of the height leaving the width constant as shown in fig. 6. Nine (9) images were generated from the original. On table 6, the same algorithm was applied on the images and a new set of BMI was produced.

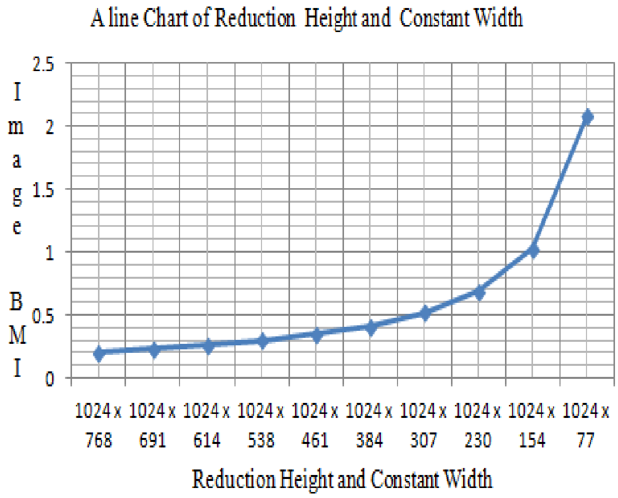

Fig.7. BMI for Height Reduction with Permanent Width

Table 6: Reducing Height with Width Permanent

Image	Height	Width	Reduction 10%	Body Height	Body Area	BMI
1.0	768	1024	768 x 1024	390	31477	0.207
0.9	691	1024	691 x 1024	351	28344	0.230
0.8	614	1024	614 x 1024	312	25177	0.259
0.7	538	1024	538 x 1024	273	21987	0.295
0.6	461	1024	461 x 1024	233	18831	0.347
0.5	384	1024	384 x 1024	195	15639	0.411
0.4	307	1024	307 x 1024	155	12502	0.520
0.3	230	1024	230 x 1024	116	9325	0.693
0.2	154	1024	154 x 1024	77	6132	1.034
0.1	77	1024	77 x 1024	38	3002	2.079

Merging of reducing Width with constant height and reducing Height with constant width are shown in table 7.

Table 7: Width and Height Reductions

Image	BMI – W	BMI – H
1.0	0.21	0.21
0.9	0.19	0.23
0.8	0.16	0.26
0.7	0.14	0.30
0.6	0.12	0.35
0.5	0.10	0.41
0.4	0.08	0.52
0.3	0.06	0.69
0.2	0.04	1.03
0.1	0.02	2.08

International Journal of Artificial Intelligence and Mechatronics
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Merging of reducing Width with constant height and reducing Height with constant width clearly shown in table 7 and figure 8.

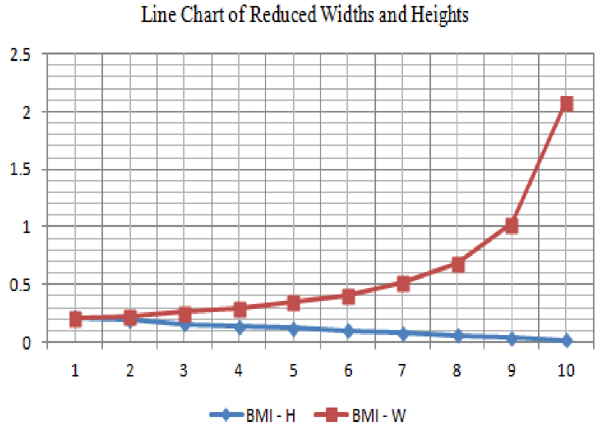

Fig. 8: A chart of Reduced Width and Reduced Height

V. Results

The results of using the image processing techniques to determine the Weight (area occupied by a silhouette in terms of pixels) and the height (i.e. distance between the highest pixel and the lowest pixel) and the subsequent calculation of the BMI (IBMI) is shown in table 8.

Table 8: Calculating BMI using Image Processing Techniques

CONVENTIONAL BMI					IMAGE PROCESSING BMI							
S/N	Weight (in Kg)	Height (in m)	Height² (m²)	BMI (kg/m²)	S/N	Image (W)	Image (W²)	Image (H)	Image (H³)	Img (BMI)	Computed BMI
1	51.5	1.57	2.4649	20.89	1	59187	3503100969	568	183250432	7.51	17.26
2	61.4	1.54	2.3716	25.89	2	70618	4986901924	584	199176704	9.84	29.13
3	72.1	1.71	2.9241	24.66	3	71973	5180112729	616	233744896	8.71	23.37
4	82.5	1.74	3.0276	27.25	4	76624	5871237376	624	242970624	9.49	27.35
5	60.9	1.75	3.0625	19.89	5	69222	4791685284	624	242970624	7.75	18.48
6	60.7	1.61	2.5921	23.42	6	83313	6941055969	664	292754944	9.31	26.43
7	60.7	1.755	3.08	19.71	7	90877	8258629129	736	398688256	8.14	20.47
8	71	1.74	3.0276	23.45	8	83321	6942389041	688	325660672	8.37	21.64
9	55	1.74	3.0276	18.17	9	80565	6490719225	704	348913664	7.31	16.24
10	76.4	1.83	3.3489	22.81	10	77954	6076826116	648	272097792	8.77	23.68
11	54.6	1.64	2.6896	20.3	11	63275	4003725625	576	191102976	8.23	20.93
12	57.6	1.6	2.56	22.5	12	64798	4198780804	568	183250432	9	24.85
13	65.1	1.82	3.3124	19.65	13	75600	5715360000	656	282300416	7.95	19.50
14	72.7	1.79	3.2041	22.69	14	74227	5509647529	624	242970624	8.91	24.39
15	81.7	1.82	3.3124	24.66	15	59448	3534064704	536	153990656	9.02	24.95
16	73	1.6	2.56	28.52	16	63969	4092032961	552	168196608	9.56	27.70
17	80.8	1.66	2.7556	29.32	17	85322	7279843684	656	282300416	10.13	30.61
18	59.6	1.68	2.8224	21.12	18	58094	3374912836	528	147197952	9.01	24.90
19	103.5	1.73	2.9929	34.58	19	66806	4463041636	552	168196608	10.42	32.08
20	68.4	1.68	2.8224	24.23	20	71209	5070721681	592	207474688	9.6	27.91
21	64.5	1.66	2.7556	23.41	21	60816	3698585856	576	191102976	7.6	17.72
22	37.1	1.43	2.0449	18.14	22	55269	3054662361	544	160989184	7.45	16.95
23	73.4	1.62	2.6244	27.97	23	82171	6752073241	640	262144000	10.12	30.56
24	33.6	1.42	2.0164	16.66	24	54539	2974502521	552	168196608	6.95	14.41
25	21.8	1.19	1.4161	15.39	25	43384	1882171456	496	122023936	6.06	9.87
26	16.3	1.01	1.0201	15.98	26	38167	1456719889	424	76225024	7.51	17.26
27	72.5	1.75	3.0625	23.67	27	75564	5709918096	616	233744896	9.6	27.91
28	73.6	1.65	2.7225	27.03	28	84726	7178495076	664	292754944	9.63	28.06
29	60.4	1.63	2.6569	22.73	29	71664	5135728896	624	242970624	8.3	21.28
30	81.8	1.64	2.6896	30.41	30	75281	5667228961	616	233744896	9.52	27.50
31	74.1	1.63	2.6569	27.89	31	79072	6252381184	616	233744896	10.51	32.54
32	149.5	1.81	3.2761	45.63	32	103487	10709559169	696	337153536	12.48	42.58

VI. Discussion

The proposed test is the Pearson's Correlation Coefficient. This method was chosen because it displays a measure of association for interval level variables. Pearson's correlation coefficient ranges from -1.0 to +1.0. On table 8 each row of data refers to an individual respondent which was entered into a SPSS data file for computation. The conventional BMI, image processing BMI and the computed BMI are shown in table 9.

Table 9: Values of Conventional and Image Processing BMI

S/No	Conventional BMI	Image Processing BMI	Computed BMI
1	20.89	7.51	17.26
2	25.89	9.84	29.13
3	24.66	8.71	23.37
4	27.25	9.49	27.35
5	19.89	7.75	18.48
6	23.42	9.31	26.43
7	19.71	8.14	20.47
8	23.45	8.37	21.64
9	18.17	7.31	16.24
10	22.81	8.77	23.68
11	20.3	8.23	20.93
12	22.5	9	24.85
13	19.65	7.95	19.5
14	22.69	8.91	24.39
15	24.66	9.02	24.95
16	28.52	9.56	27.7
17	29.32	10.13	30.61
18	21.12	9.01	24.9
19	34.58	10.42	32.08
20	24.23	9.6	27.91
21	23.41	7.6	17.72
22	18.14	7.45	16.95
23	27.97	10.12	30.56
24	16.66	6.95	14.41
25	15.39	6.06	9.87
26	15.98	7.51	17.26
27	23.67	9.6	27.91
28	27.03	9.63	28.06
29	22.73	8.3	21.28
30	30.41	9.52	27.5
31	27.89	10.51	32.54
32	45.63	12.48	42.58

The descriptive statistics of image BMI and the conventional BMI are shown on figure 10.

Table 10: Descriptive Statistics of IBMI and BMI

	N	Mean	Std. Deviation
BMI	32	24.0194	5.960068
Image BMI	32	8.8362	1.27454
Valid N (list wise)	32		

Table 11: Correlation Analysis

		BMI	ImageBMI
BMI	Pearson Correlation	1	.909
	Sig. (2-tailed)		.000
	N	32	32
Image BMI	Pearson Correlation	.909	1
	Sig. (2-tailed)	.000	
	N	32	32

**correlation is significant at the 0.01 level (2-tailed

In table 11, a Pearson product-moment correlation coefficient was computed to assess the relationship between the Conventional BMI and BMI calculated using image processing techniques. There was a positive correlation between the two variables, $r = 0.909$, $N = 32$, $p = 0.000$. A scatterplot summarizes the results (figure 9). Overall, there was a moderate, positive correlation between the conventional BMI and the image processing BMI

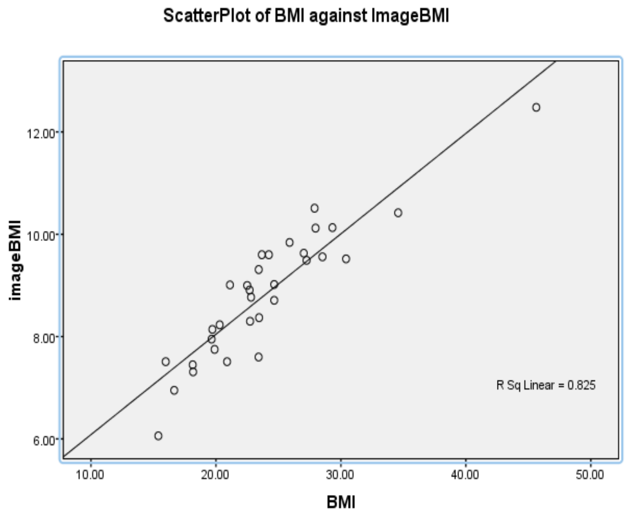

Fig.9. Scatter Plot of IBMI against BMI

The scatterplot in figure 9 appears to follow a general positive linear trend. There is no violation of the linearity assumption. The Pearson's R is then used to obtain the correlation coefficient which will indicate the strength of the relationship between Image processing BMI (labeled as IBMI) and the conventional BMI (labeled as BMI). A case processing summary is taken to reveal the percentages of the valid and missing numbers of participants as shown in table 12.

Table 12: Case Processing Summary

	Cases					
	Valid		Missing		Total	
	N	Percent	N	Percent	N	Percent
BMI*image BMI	32	100%	0	0%	32	100%

Table 13: Symmetric Measures

	Value	Asymp. Std. Error	Approx T^c	Approx Sign
Interval by Interval Pearson's R	.909	.028	11.909	$.000^c$

Ordinal by Ordinal Spearman's R	.903	.033	11.45	.000[c]
N of Valid Cases	32			

a. Not assuming the null hypothesis
b. Using the asymptotic standard error assuming the null hypothesis
c. Based on normal approximation

From table 13, it shows that (r = 0.903, p = 0.000, N = 32). Firstly, since $p < 0.01$, there is very strong evidence against H0 (i.e. we reject the null hypothesis). There is significant evidence to prove otherwise. The Pearson's correlation coefficient of 0.501 indicates a moderate positive relationship between the Image Processing BMI and the conventional BMI. Thus, we conclude that there is a relationship between a person's conventional BMI and Image Processing BMI.

Knowing that there is a linear, but moderate relationship between a person's conventional BMI and Image Processing BMI, a linear regression line is plotted. ANOVA (table 14) and a Coefficent table (table 15) are computed to show the statistics of the research.

Table 14: ANOVA

Model	Sum of Squares	df	Mean square	F	Sig
Regression	41.566	1	41.566	141.833	.000
Residual	8.792	30	.293		
Total	50.358	31			

a. Predictors: (Constant), BMI
b. Dependant Variable: imageBMI

Table 15: Coefficients

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig
	B	Std. Error	Beta		
(Constant)	4.123	.407		10.123	.000
BMI	.196	.016	.909	11.909	.000

a. Dependent Variable:imageBMI

Linear Regression Line
IBMI = 0.196(BMI) + 4.123

In short, an individual's conventional BMI is related to his/her Image Processing BMI.

The proposed method for this study was to determine the BMI of people using image processing techniques. To accomplish this goal it became necessary to reach some prerequisite goals:

Take the photograph of respondents using a digital camera, convert the captured image into a silhouette, obtain the height of the silhouette, determine the height of the silhouette (the difference between the highest pixel and the lowest pixel), obtain the volume occupied by the silhouette (i.e. number of pixels that the silhouette contains) using image processing techniques within MATLAB and, the subsequent calculation of BMI using the volume and height from above.

Using the above steps, the BMI obtained for the sample was compared to the conventional BMI. The comparison was done using Pearson's moment correlation coefficient, (r), after the scatterplot proved that there was a positive correlation between the variables. Evidence shows that there is a moderate positive correlation between the conventional BMI and the Image Processing BMI. This shows that with appropriate personnel and training, the image processing techniques for finding the BMI can replace the conventional BMI techniques.

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University: Kwame Nkrumah University of Science and Technology (KNUST), Kumasi
Qualification: PhD(Computer Science)

Mr. Joseph Kobina. Panford
Position: Lecturer
University: KNUST-Kumasi
Qualification: MSc (Software Technology)

Mr. Obed Appiah
Position: Lecturer
University: University of Energy and Natural Resources
Qualification: Mphil (Computer Science)