# Automatic Estimation of Human Weight From Body Silhouette Using Multiple Linear Regression

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***Abstract*—Estimating weight based on 2D image is advantageous especially for contactless and rapid measurement. Several researches used additional thermal camera or Kinect camera, required subjects to do front and side pose and manually extract body measures. This research propose an algorithm to estimate body weight automatically using 2D visual image where subject only do front pose. This research studied 4 features of body measures which are: (F1) height, and width of (F2) shoulder, (F3) abdomen/waist plus arm, (F4) feet. Each feature was simply subtracted based on body proportion where normal body has 8 equal segments. Shoulder is in 2nd segment, abdomen/waist is in 4th segment and feet is in the last segment. Multiple Linear Regression is used to determine weight estimation formula of all combination of 4 features, 15 in total. The highest significance R2 (0.80) and RMSE 2.68 Kg is given when using all 4 features in the estimation formula.**

***Keywords— Body weight, Silhouette, Image processing, Multiple Linear Regression***

## I. INTRODUCTION

Image have been used to estimate variables such length, height, distance and area. The estimation required the algorithm to set a pixel-to-cm ratio beforehand. Camera has promoted a non-contact estimation that is essential in non-destructive measurement. It also enable a remote estimation or analysis.

Moreover, researcher has extended the measurement into indirect variables such volume and weight. The estimation basically utilize length or area which then calculate those indirect variables using regression, formulae or an artificial intelligence algorithm.

Research by [1] has uniquely measure volume of a food bowl using cutleries as reference. A pair of chopstick where each was placed on top of the container and on table is proposed to measure its height. Diameter of the container was estimated based on comparison to the actual length of chopstick that was placed on top. Once its diameter and height is estimated, volume of container was calculated using volume of spherical cap formulae.

A volume estimation using image also has been proposed by [2] to measure volume and mass of citrus fruits. The volume is measured in assumption that the fruit was constituted from several elliptical frustums. Each frustums's volume is calculated based on two diameters that was pictured by two cameras in perpendicular arrangement. The mass was measured using correlation formulas between volume to its actual mass and showed high correlation.

The correlation formulas between body traits and body weight has also been proposed by [3]. The research used lateral body surface (BSS) of rabbits to estimate Live Weight (LW) and Carcass Weight (CW) through regression method. Research by [4] investigated 23 indexes from various body surface measure (weight, height, area, difference) of cattle's thorax, abdomen, chest, dorsal and body. A linear regression was also used to find formulas between body weight and the indexes. The research found 6 formulas that has high correlation.

Another recent study that use a regression to estimate weight using anthropometry measurement was suggested by [5]. It used various of regression which were Linear regression, Support Vector Regression, Gaussian Process Regression and Neural Network Regression. The highest accuracy was given by circumference of waist, buttock, thigh and arm, height, gender and ethnicity with confidence interval of 98% with limits of 1.80 Kg and 2.25 Kg when using Gaussian process Regression. The study was used the National Health and Nutrition Examination Survey (NHANES) and US. Army Anthropometry Survey.

The object's weight estimation through image analysis is a helpful method for example when the object are hard to be moved. In emergency room, moving patients to normal scale for weight measurement are mostly harmful to their condition. Whilst weight measurement is essential for calculating dosage of drugs given [6]. Thus research by [7] proposed a bedside weight estimation from abdominal and thigh circumference. The formula for Actual Body Weight (ABW) of male and female are determined by multiple linear regression that was evaluated by correlation for the best formula.

In weight estimation of human body, [8] also investigated 127 combinations ($2^7$-1) from 7 body measures which were height, upper-leg length, calf circumference, upper-arm length, upper-arm circumference, waist circumference, upper leg circumference. The combinations result formulas that was determined using least square method. This study also proposed to use 2D image of human front and side portrait. Since 2D image could not measure circumference, the study propose to measure the width as an equal to diameter of a cylindrical approximation. The study also suggested to take out measurement of calf as this part was poorly affected by loose clothing which hid the actual body measures. List of body surface measures that have been proposed by several researches are shown in Table 1. Those

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measures gives insight to what have worked out to estimate human body weight.

All above methods to estimate weight of human body was performed manually in 2D images. Operators still have to count pixels for height, length or circumference manually using visual. In this research, an automatic weight estimation was developed. The developed method would be beneficial for non-contact and computerized measurement of body-weight. The implementation is numerous. It can be applied in health service, public place, surveillance, intruder detection or even for casual implementation in mobile application.

TABLE I
LIST OF BODY SURFACE MEASURE FOR WEIGHT ESTIMATION

| Reference | Body Surface Measure |
|---|---|
| Giles N Cattermole, et. al., 2016 [9] | Middle-Arm Circumference (MAC) |
| Robert G. Buckley, et. al., 2011 [7] | – Abdominal Circumference (AC)<br>– Thigh Circumference (TC) |
| Carmelo Velardo, et. al., 2010 [6] | – Height<br>– upper-leg length<br>– calf circumference<br>– upper-arm length<br>– upper-arm circumference<br>– waist circumference<br>– upper leg circumference |
| Ana Paula Ferreira melo, et. al., 2014 [10] | Man:<br>– arm circumference<br>– abdominal circumference<br>– calf circumference<br>Women:<br>knee height |

The research used only measure of body part that was not affected by loose clothing as suggested by [9]. The actual body weight was measured by normal scale. Each variables were extracted automatically using image processing algorithm. This research utilizes visible light camera, rather than Kinect or thermal camera as in [10] and [11]. The visible light camera is cheaper and simpler to operate.

## II. METHOD

Since the estimation algorithm uses 2D RGB image where people using their regular clothing, body measure chosen should mind this condition. Loose clothing could give additional width to horizontal measures. Hence people were asked to pose straightly towards camera, lay their both hand closely to their body, and stick their leg and feet closely during data acquisition.

Top outfits such shirt or blouse does not add additional width when the arm are placed tightly to the body. Hence horizontal measure in the upper body part such waist or abdominal plus the attached arm in Table 1 were used as features. Arm by itself were not used as features since it is tedious to be segmented as it stick to body. Shoulder horizontal measures also added to feature list as its width is rarely affected by clothing. Nevertheless, a very loose or puffy clothing should be avoided during data acquisition since it would show longer width of shoulder and waist/ abdomen even though the arm was placed tightly to the body.

Bottom outfits such trouser and skirt sometimes appears to be loose even when leg were stick closely. Hence horizontal measures in the lower part of body such thigh, upper-leg, calf as in Table 1 were taken out from feature list. Nevertheless, ankle most of the time shows original width even when the person were wearing foot covers. Height as in Table 1 is used as feature since vertical measure is not affected by clothing. Features for weight estimation using 2D images that was proposed in this study is listed in Table 2.

TABLE II
LIST OF BODY SURFACE MEASURE FOR WEIGHT ESTIMATION IN THIS RESEARCH

| | |
|---|---|
| F1 | Height |
| F2 | Shoulder width |
| F3 | Abdomen/waist plus attached arm width |
| F4 | Feet Width |

### A. *Features Extraction Using Body Proportion*

Distance between person and camera were fixed to 2 meters to ensure standardized pixel size. This research simply used human body silhouette as input. Height is distance between the highest and lowest vertical coordinates of human body silhouette.

To locate shoulder, abdomen/waist plus arm and feet, a human body proportion were used. In normal human, the body is divided into 8 equally vertical segments where shoulder is located in second one-eight segment, abdomen/waist plus attached arm is located in fourth one-eight segment, and feet is in lowest one-eight segment [12]. First and second body feature were assumed to be the largest width in each segment, whilst the third body feature was assumed to be the narrowest in the segment. Figure 1 show the eight segments drawn over an example of human body and its respective features. The border of each segment is shown as line, body features are shown in bolder white line.

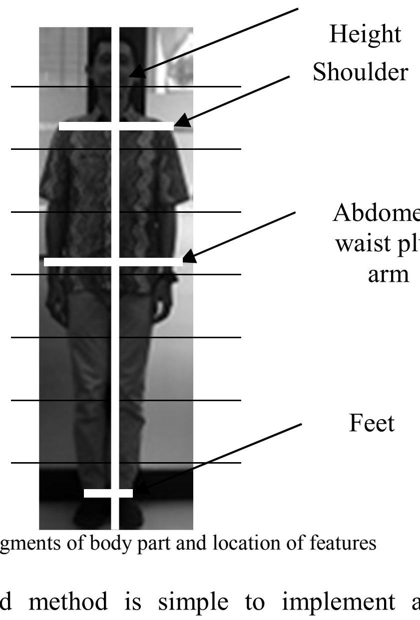


Fig. 1 Eight segments of body part and location of features

The suggested method is simple to implement and require minimum computation. Width of each vertical coordinates were calculated as distance between minimum and maximum horizontal coordinates of the body's edge. The widest width was calculated as maximum of distances in its segment, whilst the narrowest width was calculated as minimum of distance in its segment. The pseudocode for feature extraction is shown in Figure 2.

**Input** human body silhouette
Divide silhouette into 8 equal horizontal segments
    For each segment
        Count white pixel's width in every rows
    End
Determine shoulder's width as the widest white pixel in 2nd segment
Determine abdomen/waist plus arm's width as the widest white pixel in 4th segment
Determine leg's width as the narrowest white pixel in 8th segment
**Output** width of shoulder, abdomen/waist, leg

Fig.2 Pseudocode for feature extraction

*B. Weight Estimation using Multiple Linear Regression*

A Multiple Linear Regression predicts future outcome by determining the trend of existing data that has multiple inputs. It assumes that the data has linier trend between inputs and output. The equation for multiple regression is in Equation 1, where $i$ is number of data, $b_0$ is regression intercept, $b_j$ is $j$-th predictor's regression slope, $x_{ij}$ is $j$-th predictor for the $i$-th observation.

$$Y_i = b_0 + \sum_{j=1}^{n} b_j x_{ij} . \qquad (1)$$

The predictor's regression intercept and slope $b$ is calculated using matrix of predictors $x$ and actual outputs $y$ using Equation 2.

$$b = (x^T x)^{-1} x^T y \qquad (2)$$

Multiple linear regression from all combination of 4 measures to body weight were investigated. The total combination is 15 as a power-set of 4 minus the null set ($2^4$-1 = 15). A coefficient of determination, $R^2$ was used to measure how well the regression to fit the data. It is a measure of sum-squared of residual (error of estimation) compare to proportional variance of predictors. The value range from 0-1 where the best fit of regression has value of one and the worst is zero. It is calculated using Equation 3.

$$R^2 = 1 - \frac{\sum_{j=1}^{n}(Y_i - y_i)^2}{\sum_{j=1}^{n}(y_i - \bar{y})^2} \qquad (3)$$

## III. Result and Analysis

The algorithm was tested in 10 adults male. Some images of human body silhouettes are shown in Figure 3. The silhouettes were made by performing segmentation on human body from its background.

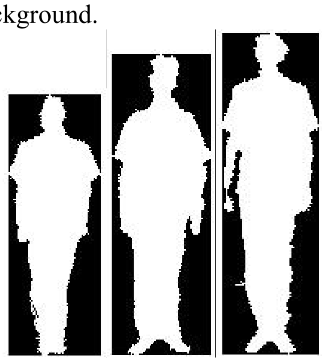

Fig. 3 Some images of human body silhouette

Body features from each silhouette was then extracted using the developed method where the result is shown in Table 3. Each is in standardized pixel unit.

TABLE III
Body Feature from Data

| No | F1 | F2 | F3 | F4 | Actual Weight (Kg) |
|---|---|---|---|---|---|
| 1 | 176 | 52 | 53 | 15 | 70 |
| 2 | 192 | 48 | 57 | 26 | 71 |
| 3 | 192 | 51 | 59 | 20 | 76 |
| 4 | 197 | 52 | 48 | 19 | 81 |
| 5 | 198 | 54 | 54 | 17 | 67 |
| 6 | 209 | 54 | 55 | 16 | 58 |
| 7 | 194 | 52 | 54 | 22 | 78 |
| 8 | 185 | 48 | 58 | 21 | 60 |
| 9 | 200 | 51 | 52 | 15 | 65 |
| 10 | 197 | 53 | 57 | 25 | 85 |

Each feature's correlation coefficient towards actual weight, *r*, was calculated. The correlations were tested to check which feature has more similar trend towards actual weight. The rule of thumb in correlation is that $r > 0.5$ means the correlation is strong. A strong correlation means a change in a feature would result a correct prediction in the actual weight. Although correlation cannot be interpreted as causation, the test can be used to test whether both variables fluctuate together. The result in Table 4 shows that only F4 has strong correlation with the actual weight.

TABLE IV
Correlation Between Feature and Actual Weight

| No | Feature | *r* |
|---|---|---|
| 1 | F1 | -0.07 |
| 2 | F2 | 0.27 |
| 3 | F3 | -0.06 |
| 4 | F4 | 0.54 |

A linear regression between feature F4 and actual weight are then calculated. It result a weight estimation formula of $Weight = 47.45 + 1.2\ F1$. This formula was tested in all 10 silhouette and gave RMSE between actual and predicted weight of 6.18 Kg. Although the correlation is low, a weight estimation formula on feature F2 was also calculated. It result a formula of $Weight = 11.97 + 1.15F3$ and gave RMSE between actual and predicted weight of 7.15 Kg.

Since RMSE of using one feature is still high, a Multiple Linear Regression using all 15 combination of 4 features is performed. The result of each formula along with $R^2$ (98% confidence interval) and its Root Mean Squared Error (RMSE) between actual and predicted weight is shown in Table 5.

As listed in Table 5, the highest $R^2$ belongs to formula number 15 where all features were used in the regression. Formula (15), is then selected as the formula for estimating weight as it gives higher correlation. It uses feature of height, and width of shoulder, waist and feet. The RMSE is 2.68 Kg and the percentage error is 3.8% than the actual weight. The RMSE is similar to study in [5] which in the limit of 1.80 Kg and 2.25 Kg in CI 98%. Although the performance is slightly hinger, this study proposed an automatic and contactless measurement compare to previous study that require a contact measurement that require longer time to collect all features.

The percentage error is also similar to estimation result conducted by [6] which was ±5%. Although the performance is similar, but the proposed method in this study excel it since it only use features from frontal pose of the body compare to study in [6] which use features from side and frontal pose. The plot of estimated weight and actual weight using Formula (15), Weight = -23.62 - 0.37 F1 + 3.34 F2 – 0.93 F3 + 2.33 F4, is shown in Figure 4.

TABLE V
WEIGHT ESTIMATION FORMULA, ITS $R^2$ AND RMSE

| No. | Feature Used | Formula | $R^2$ | RMSE (Kg) |
|---|---|---|---|---|
| 1 | F1 | Weight = 72.47 – 0.1 F1 | 0.00 | 7.13 |
| 2 | F2 | Weight = 11.97 + 1.15 F2 | 0.07 | 7.44 |
| 3 | F3 | Weight = 80.61 - 0.17 F3 | 0.00 | 7.15 |
| 4 | F4 | Weight = 47.45 + 1.21 F4 | 0.29 | 6.18 |
| 5 | F1, F2 | Weight = 28.30 - 0.18 F1 + 1.51 F2 | 0.10 | 7.62 |
| 6 | F1, F3 | Weight = 84.35 - 0.02 F1 - 0.18 F3 | 0.00 | 7.16 |
| 7 | F1, F4 | Weight = 41.77 + 0.03 F1 + 1.21 F4 | 0.29 | 6.25 |
| 8 | F2, F3 | Weight = 2.87 + 1.21 F2 + 0.11 F3 | 0.08 | 7.43 |
| 9 | F2, F4 | Weight = -105.12 + 2.71 F2 + 1.86 F4 | 0.62 | 4.47 |
| 10 | F3, F4 | Weight = 101.97 – 1.17 F3 + 1.68 F4 | 0.43 | 13.46 |
| 11 | F1, F2, F3 | Weight = 18.40 - 0.18 F1 + 1.57 F2 - 0.12 F3 | 0.10 | 7.61 |
| 12 | F1, F2, F4 | Weight = -82.34 - 0.35 F1 + 3.54 F2 + 2.01 F4 | 0.71 | 3.19 |
| 13 | F1, F3, F4 | Weight = 107.11 - 0.02 F1 – 1.18 F3 + 1.68 F4 | 0.43 | 5.37 |
| 14 | F2, F3, F4 | Weight = -51.20 + 2.48 F2 – 0.87 F3 + 2.16 F4 | 0.69 | 3.96 |
| 15 | F1, F2, F3, F4 | Weight = -23.62 - 0.37 F1 + 3.34 F2 – 0.93 F3 + 2.33 F4 | 0.80 | 2.68 |

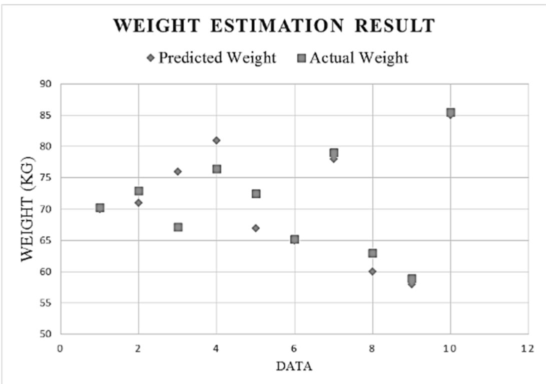

Fig. 4 Result of predicted and actual weight

## IV. CONCLUSION

An automatic weight estimation using only frontal silhouette of human body has been proposed in this research. The features extracted was chosen where usually it is not be affected by daily clothing that could give additional width. The best estimation formula utilizes feature of height, width of shoulder, abdomen/waist plus arm and feet with high significance $R^2$. The developed algorithm enable estimation of human body weight using image that is non-contact and simple. Further investigation to estimate weight in various condition among ages, gender and ethnic should be carried out to test the algorithm in various body silhouette.

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