DEVELOPMENT OF MATHEMATICAL MODEL AND SOFTWARE FOR DIGITAL CIRCUMFERENCE ANTHROPOMETRIC MEASUREMENT

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ABSTRACT

Digital measurement based photography dominated anthropometry measurement research lately and shift conventional measurement methods but previous research still study only tight clothes and not for veiled woman. This research was conducted 150 respondents, two methods measurement (conventional and digital) and 11 area measurements. Result of anthropometry measurement using mathematic model show that R-Squared average each type of respondents without belt is 0.69 (men), 0.64 (veined women), and 0.71 (women). This research is better than previous study that used elliptical model mathematic to measure all same points measurement because BMI factor actually effect to measure circumference of human body.

Keywords*: conventional and digital measurement, Body Mass Index, R-Squared*

1. INTRODUCTION

Ergonomics have basic principles to design a working system to fit human characteristics or human work limitations (fit the job to the man) so the work safer, maintained health and finally it will increase the productivity. One of ergonomics aspect that supports products design and work systems, it is anthropometry physic.

Anthropometry is one of ergonomics science that studies human body dimensions and their measurement data and useful for determining physical geometry, mass and power of human body that are useful in the process of designing a product so inappropriate product size with user size can be avoided (Grandjean, 1980) .

Anthropometric measurements developments beginning with conventional measurements using simple tools, such as spreading and sliding calliper, anthropometer, simple scales, measuring tape, etc. (Pulat, 1992). Actually, conventional measurements are impractical, expensive, and less reliable so it needs to do improvement.

In order to solve these problems, around 1970 years emerged photography method using a digital camera as an alternative anthropometric measurement. The principle of this method is digital cameras produce digital images that can be processed, stored and transmitted electronically so it will get better information, and more efficiently. Anthropometric measurements digitally circumference has been widely used in industrial clothing , shoes , helmets , textiles, etc. (Hung et al , 2004) .

Designing of machine or equipment that appropriate with human anthropometry encourage increased research in this area, one of those research conducted by Liliana et al (2007) which discusses background work processes accidents caused by tool that has designed is inappropriate to physical condition of man, so appears some data that need to be considered for designing the product.

Research about product design also examined from of mathematical modelling view that has been done by previous research. This research was started in 1950s by determinate anthropometry parameters in body segment which obtained from direct measurement on an old dead man and then developed several other studies using regression functions for

anthropometry human body modeling (Nikolova and Toshev, 2007). The objective research of anthropometric mathematical modeling have wide variations both in terms of methods, tools, measurement variables, population studied, and its purpose.

Some research by developing image processing methods using a digital camera done by Januar (2010), involving 60 anthropometric variables is linear and Marti (2010) which utilizes a GUI in software development to recognize images of human faces using Eigenfaces method and it aims to maximize the variance. The results of testing and test analysis of face image recognition software of using Eigenfaces method is obtained that the optimal recognition rate achieved is 75%. The study design was also performed by Meunier and Yin (2000) who compare conventional measurement method and three-dimensional measurements method of clothing that covers 5 variables anthropometric and majority of the measurements is in circumference. Another research also conducted utilizing digital image was done by Probandari (2010), involving 11 anthropometric variables related to human body circumference and using equations ellipse, circle and rectangle mathematical model. The results of this study show an elliptical equation has a smaller error than other mathematic model but still looks great error on the waist and hip circumference measurements. Usability of software was also low performance, it proved by rigidity of software such as input subject data, how to use image processing software and less information about anthropometric circumference measurements instructions so user still confuse to use this software.

Some of mathematical modeling research have been conducted, one of them is Satriawan (2010) by using a linear regression model, parameters proportion, Park and Nurmianto methods that involving 289 female subjects and 522 male subjects and these four methods were compared based on Mean Absolute Error (MAE) and Mean Square Error (MSE) value using ANOVA. The mathematical modeling study was also performed by Fitralisya (2011) who built several mathematical models anthropometric circumference and involving 44 subjects. This research followed by Kusumadewi (2011) to construct linear equations models that represent a waist and hips circumference anthropometric variables by input independent variable, doing approaching of a circle, ellipse, length and width on hips , length and width on waist and then to find out correlation its input and regression.

2. THEORETICAL BACKGROUND

2.1 Digital Circumference Anthropometric Measurement

Circumference measurement is one of human body variables that can be measured, defined and standarized. This variabel can be done by taking a subject image from front and size direction. These directions are being two basic points to facilitate circumference calculation of human body.

Based on the ISO / TC 159 (ISO 15534 & ISO 9241), body size data collection (anthropometric) measurements ideally performed with a static method at least meet the two conditions are subject were measured in naked (nude person) and measurements were made with ignoring body movement , clothes , equipment used and working condition.

There are two techniques anthropometric measurement; conventional and digital. Conventional measurement are performed directly on the object by measuring limb . The equipment needed for this measurement such as chair, meter, and calipers and etc. This technique is more easily to implement and cheap but need more time, more labor-intensive , and difficult to perform anthropometric measurements for huge samples.

Digital measurement is indirect measurement that made by photographic methods such as cameras , computers , etc. Generally, digital measurement is not consume a lot of time and effort , ideal for making large quantities of anthropometric measurements and eliminating direct contact with the subject.

2.2 Digital Image Processing

Digital Image processing (Probandari , 2009) is a input signal form such as a photograph or video frames . Output of this

processing is characteristics or parameters related to image (shown Figure. 1). Most of image processing technique is to create an image as a two -dimensional signals and applying standard signal processing.

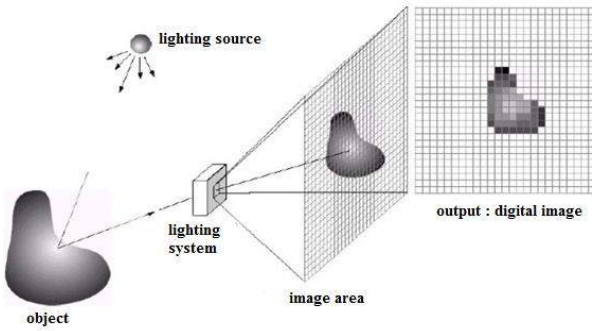

Figure 1. Digital Image Processing

Parameter is can be data measurement such as wide area, weight and etc. There are four items that be consideration in digital image processing relation to the parameter are :

a. Accuracy
b. Validity and reliability
c. Error
d. Callibration

2.3 Correlation and Linear Regression

Linear correlation analysis illustrates the linear relationship between two variables or more without previously unknown whether one variable is affected by other variables. Linear regression is divided into two types:

a. Simple linear regression
   The general equation for simple linear regression is:
   $y = a + bx$ (1)
b. Multiple linear regression

If the simple regression there is only one dependent variable (Y) and an independent variable (X), then in the case of multiple regressions, there is one dependent variable and more than one independent variable. In business practice, multiple regressions was more widely used, as well as the number of variables in the business that need to be analyzed together, also in many cases more relevant to use multiple regression. The general equation for linear regression is:

$$y = a + b_1x_1 + b_2x_2 + \cdots + b_nx_n \quad (2)$$

3. RESEARCH METHOD

The objects in this research were college students (men, women and veiled women) who do not have physical disabilities, used clothing is not too loose and not use skirts for women. Objects in this study consisted of 150 respondents; 82 respondents male and 68 female respondents (with and without veil). Flow chart for the research shown in Figure 2.

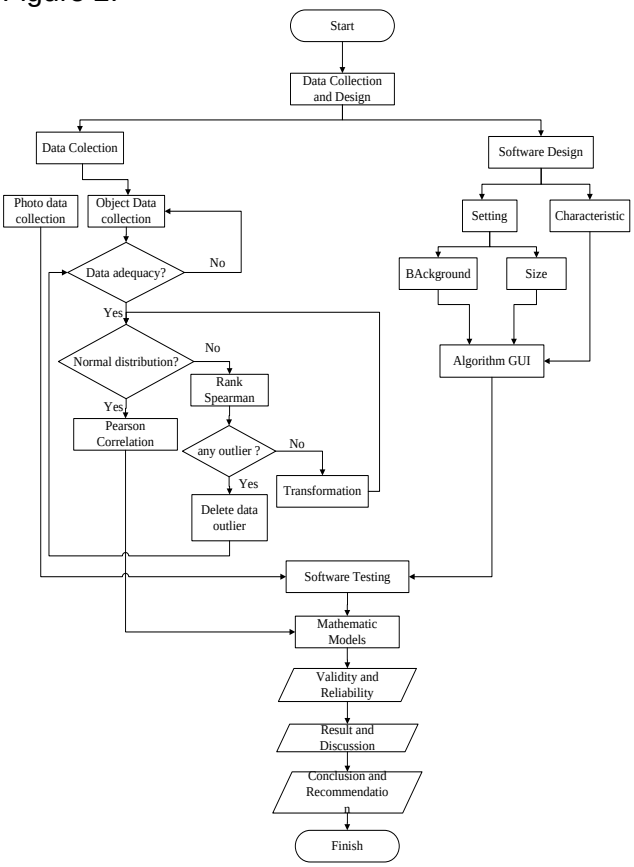

Figure 2. Research Flowchart

Explanation of flowchart research as follows:

1. Data collection is divided into two methods:
   a. Conventional measurement data (data gained from manual measurement)
   b. Digital measurement data (data gained from capture and collection photo using camera as shown in Figure 3 and have distance 1.5m.

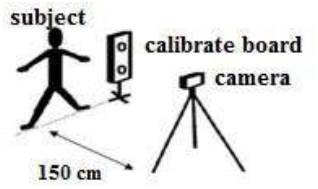

Figure 3. Digital Measurement Procedure

Data for each methode taken from 11 area in human body, shown in Figure 4

Variable	Circumference Area	Point of Measurement
X1	Forehead	
X2	Neck	
X3	Chest	
X4	Waist	
X5	Hip	
X6	Arm	
X7	Wrist	
X8	Palm	
X9	Thigh	
X10	Calf	
X11	Tarsus	

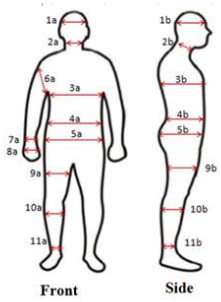

Figure 4. Measurement Area

2. Statistics Test by two process :
   a. Confidence Interval test by below formula :

$$Confidence\ Interval\ (CI) = \bar{x} \pm E \quad (3)$$

$$E = t_{\alpha,n-1}\, x \left(\frac{s}{\sqrt{n}}\right) \quad (4)$$

where :
E = max. Value of estimation error
s = deviation standard
α = significant level
n-1 = degree of freedom

If $t_{\alpha,n-1}\, x \left(\frac{s}{\sqrt{n}}\right) \leq$ E, then data is adequate.

   b. Normality test performed using Kolmogorov-Smirnov analytical test method to determine null hypothesis (H0) and alternative hypothesis (H1) and define trust or confidence level (1-α), α = 5%.
3. Correlation Test
   Correlation test is used to determine the most factors that affect to circumference variable with two hypotheses; null hypothesis (H0) and alternative hypothesis (H1) to investigate correlation of sex on body circumference and BMI to body circumference.
4. Designing Software
   The important things required in software design is settings design (background, image size, and calibration), design characteristics of background in the landmarks identification, and Algorithms on *Graphical User Interface* (GUI) based on MATLAB.
5. Mathematical Modeling
   Linear regression method of independent variable (length and width were measured digitally) and dependent (conventionally measured circumference) used in this study.
6. Validity Analysis using R-squared analysis and Reliability test with % TEM analysis (technical error of measurements):

$$\%\,TEM = \left(\frac{TEM}{mean\ 1st\ and\ 2nd\ meas.}\right) x\ 100\ \% \quad (5)$$

$$\text{TEM} = \sqrt{\frac{\sum D^2}{2N}} \quad (6)$$

where :
D = difference of two measurement result (repeating process)
N = sum of subject

4. RESULT AND DISCUSSION

4.1 Statistic Result

The adequacy test is done by comparing E value standard deviation of average value on n number of samples. The result shows that data is adequate for Normal BMI (men, women, and women are veiled),Underweight BMI(men, women), and Overweight BMI (male).

The normality test using Kolmogorov-Smirnov method shows that significance value of each variable is greater than α (Sig.> 0.05) so H_0 data that came from a normally distributed population fail to rejected.

4.2 Correlation Result

Product moment correlation test results show that H_0 hypothesis 1 and 2 fails to rejected (Sig.> 0.05) because there is no significant relationship between BMI with a circumference forehead and H_0 hypothesis 13 was rejected because there is a significant relationship between BMI with neck circumference (Sig < 0.05). H_0 Hypothesis at 1 and 2 failed to be rejected because there is no significant relationship between sex with her forehead and neck circumference (Sig> 0.05) so that only one

model is used on the forehead circumference measurements for all sexes.

4.3 Design Software Result

The development of software digital antropometer CAM is named Sofie (Circumference Anthropometry Measurement Software for Industrial Engineer) that have functions inside, there are insert image format *. Jpg, image calibration, measurement and determination of measurement points and send data from the CAM SofIE to Ms. Excel. View Sofie CAM software such as GUI (Graphical User Interface) Matlab consists of several windows, namely: Welcome Windows (version), Identity Windows (data subject), Front Facing Window (measurement front) and Side Window Facing (measurement side view).

4.4 Linear Regression

In this study, there are two variables that are used for linear regression are:

a. Dependent variable is x value of conventional measurement
b. Independent variable is length (a) and width (b) of digital measurement.

There are 66 mathematic model have been generated and then will implement in software. Sample mathematical model results are shown on Table 1.

Table 1. Example of Mathematical Model Men without Belt

Sex	Variable	Area	Equation
Man w/o belt	X1	Forehead	44.53 + 0.56 a + 0.24 b -0.05 BMI
	X2	Neck	18.18 + 1.13 a +(-0.13 b) + 0.35 BMI
	X3	Chest	32.69 + 0.48 a + 0.96 b + 0.72 BMI
	X4	Waist	(-4.57) + 0.77 a + 0.66 b + 1.50 BMI
	X5	Hip	30.11 + 5.66 a + 0.52 b + 1.50 BMI
	X6	Arm	5,94 + 0.56 a + 0.35 b + 0.54 BMI
	X7	Wrist	18.06 + 0.11 a+(-0.83 b)
	X8	Palm	12.23 + 0.48 a + 0.76 b
	X9	Thigh	(-5.15) + 0.84 a + 1.19b + 1.19 BMI
	X10	Calf	10.51 +(-0.06 a) + 0.61 b + 0.84 BMI
	X11	Tarsus	11.74 0.41 a + 0.24 b + 0.31 BMI

4.5 Accuration and Reliability Test

Table 2 shows that R-squared between direct measurements and digital measurements with no belt close to 1, although there are some areas of measurement like palm area has a lower R-Squared value. The decline occurred in studies using accuracy and no seat belt caused by use of long-sleeved shirt, double dress pants and loose trousers.

Table 2. R-*Squared* with and without belt for Normal BMI

Item	Man-M		Woman-W		Woman (veil)-V	
	W/o belt	Belt	w/o belt	Belt	w/o belt	Belt
X1	0.575	0.772	0.81	0.965	0.54	0.865
X2	0.985	0.881	0.755	0.869	0.522	0.906
X3	0.731	0.881	0.7	0.872	0.736	0.926
X4	0.764	0.906	0.751	0.949	0.738	0.937
X5	0.766	0.894	0.743	0.919	0.697	0.916
X6	0.607	0.861	0.82	0.812	0.654	0.715
X7	0.669	0.892	0.6	0.917	0.506	0.879
X8	0.634	0.633	0.584	0.827	0.534	0.858
X9	0.72	0.846	0.605	0.804	0.74	0.785
X10	0.71	0.651	0.694	0.802	0.71	0.91
X11	0.504	0.829	0.729	0.843	0.618	0.898
Mean	0.697	0.822	0.708	0.871	0.636	0.872

Table 3 shows that using TEM formulation obtained the biggest measurement error in veiled Women with Normal BMI ranges is 2.07%. This occurs in the neck (X2) as respondents using veil with a wide range of thickness and hoods model. Each respondent make veil model with different types, different types of materials, while the measuring point by point on the edge veil image (Figure 5 arrows no.1), not on the neck exactly so that it reduces accuracy and reliability level of the device software. In veiled woman, with an arm measuring area (X7) due to a long veil that covers the arm area so measurement points as well start from outside of the hood (Figure 5 arrows no.2).

Figure 5 veiled Women Conditions

Table 3. Reliability Test Results (%TEM)

Area	BMI Normal			BMI *Underweight*		BMI *Over weight*	Mean
	M	W	V	M	W	M	
X1	0,707	1,373	0,810	1,2963	0,660	0,654	0,917
X2	1,734	1,724	2,912	1,059	1,536	1,061	1,671
X3	0,669	0,431	1,106	0,692	0,564	0,145	0,601
X4	1,173	1,131	2,076	0,744	0,626	0,748	1,083
X5	0,875	0,324	1,061	0,544	0,925	0,540	0,7121
X6	1,663	1,398	1,587	1,437	1,396	1,335	1,469
X7	1,797	1,571	1,672	2,334	1,860	1,833	1,844
X8	1,644	1,748	1,823	2,318	1,714	1,497	1,791
X9	1,763	0,704	1,022	1,232	1,716	1,039	1,246
X10	1,427	1,310	1,494	1,131	1,692	1,744	1,466
X11	1,593	1,359	1,681	1,350	1,713	1,616	1,552
Mean	1,368	1,188	1,568	1,256	1,309	1,110	1,305
Min	0,669	0,324	0,810	0,544	0,564	0,145	0,601
Max	1,797	1,748	2,912	2,334	1,860	1,833	1,849

4.6 Analysis of accuracy

Table 4 shows that all items measurements using linear regression mathematical model much better than ellipses, circles and rectangles models so linear regression mathematical model compares is better than previous studies of mathematical models. This is because of BMI has an influence factor in circumference measurements that provide improvements in accuracy levels.

Table 4. MAD Comparison

Item	Present study	Previous Study		
	Linear regression	Ellipse	Circle	Rectangle
X1	0.7491	1.4710	6.1609	71.0546

Table 4. MAD Comparison

Item	Present study	Previous Study		
	Linear regression	Ellipse	Circle	Rectangle
X2	0.9300	1.5970	11.5142	74.1679
X3	3.6433	2.6920	7.0991	134.9069
X4	3.9998	5.5220	15.5210	159.6406
X5	3.7066	3.5980	13.5308	154.3112
X6	0.9244	1.5780	3.9453	54.0188
X7	0.7945	1.4610	2.4384	25.6117
X8	0.7514	1.7890	2.0919	25.8817
X9	4.0297	2.4340	12.2277	68.6251
X10	0.9935	1.8370	2.9002	54.4744
X11	1.0359	1.5410	7.8471	53.6962
Mean	1.9598	2.3200	7.7524	79.6717

5. CONCLUSION

In general, the mathematical model anthropometric circumference measurements for all items that are developed can be said to be valid and reliable. It can be seen from the test results that showed the average yield for R-Squared 0,752 (research without belt) and 0,821 (research with belt). In addition, MAD digital measurements in this study is better compares with previous studies with an average of MAD 1,953 and previous studies using model elliptical is 2,320. This is due to BMI factors in the mathematical modeling that affect to accuracy of circumference measurement.

The research is still necessary to continue for veiled woman subject because there are measurement errors especially in the area of the neck and head. Also needs to be further research on mathematical modeling for BMI overweight female subjects.

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