The models of Relationship between Center of Gravity of Human and Weight, Height and 3 Body's Indicators (Chest, Waist and Hip)

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Received: July 16, 2019; Accepted: November 28, 2019

Abstract

Determining the position of the Center of Gravity (CoG) of the human body takes an important role in human movement analysis. Recently, there are several measurement methods to estimate the center of body point. These methods are generally costly, time consuming and complicated implementation process. In this paper, we propose a simple model that can determine the body's Center of Mass through body indicators: height, weight and three other parameters of body's measurement (sizes of Chest, Waist and Hip). From the measured data, a quick, stable and accurate model has been built, which reveals the relationship between the Center of Gravity (CoG) and the body indicators: weight, height and body measurements.

Keywords: Vestibular disorder, center of gravity (CoG), body measurement

1. Introduction

A body's Center of Gravity (CoG) is defined as the point around which the resultant torque due to gravity forces vanishes. Determining the body's CoG has many applications in recent years. In medicine, knowing the central position helps us diagnose whether the person have vestibular disorders and other diseases. In sports, in order to study the postures or movements of athletes, the focus is very important to set the standards of movements and to determine methods to achieve higher efficiency in competitions and treatment. In literature, there are many methods for determining the focal points such as digitizing (the anatomical landmarks such as the shoulder, elbow, groin, pillow ...) to create a 2D or 3D model of the body. From there, they can calculate the focus of every part of the body and the whole body. These methods are very costly and time consuming. Our methods overcomes these challenges, which have the ability of finding a center of gravity (CoG) simply and less costly.

In the collecting data and processing phase, many methods are attemped to provide the best results with the simplest implementation. Linear regression method has been used a lot in recent years due to its simplicity and accuracy. For example, in 1995, accurate diagnosis and short-term surgery results in cases of suspected appendicitis in processing the collected data [1]. In 2010, doctors used linear regression method to serve in data processing in thoracic ultrasound diagnosis [2]. This paper investigates the relationship between body parts, namely weight, height, three sizes of body's measurements and the CoG.

2. Method

In this paper, we use linear regression analysis to determine the relationship between the CoG point along the body's axis and the body's measurements. In other words, we can estimate the CoG of any given person if we know his/her body's measurement with high accuracy.

2.1. Data preparation

In this phase, the measurement process is implemented. Regarding the weight, height and sizes of body's measurement, we collected data from people aged 19-23. Everyone is in normal health condition. 90 measurements are recorded and stored in Excel.

Regarding the determination of the position of the CoG point along the body's axis, we designed a specific scale that can give the position of the humans' CoG. The subject will be guided to the correct position, where their feet are placed at the original line as in figure 1, and relaxed body when lying on the system.

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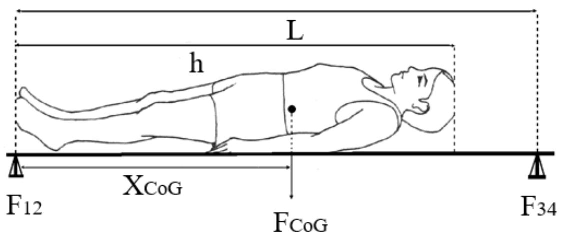

Fig. 1. Position of subject laying on scale.

The proposed model includes a mechanical system designed so that the subject can lie on it. Loadcells will be fixed at 4 legs of this system as in figure 2.

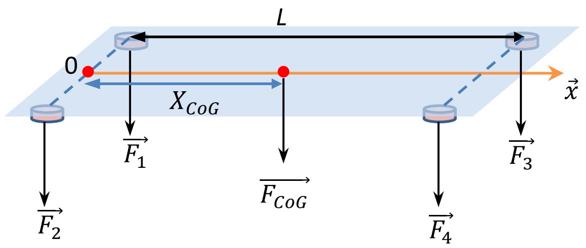

Fig. 2. The proposed scale model.

The support points 1 and 2 are placed at the original line (perpendicular with X axis), the coordinate X=0. The support points 3 and 4 are placed at the distance L from the original line (the frame length, L = 1475 mm). The body's mass F creates F_1, F_2, F_3 and F_4 forces on 4 support points.

where $F = F_1 + F_2 + F_3 + F_4$

The coordinates X_{CoG} (the coordinates of CoG point from foot) of the center of mass satisfy the condition that the resultant torque is zero:

$$T = \sum_i X_i \vec{F_i} = 0$$

$$\Rightarrow \quad 0\,(F_1 + F_2) + L(F_3 + F_4) - X_{CoG} F = 0$$

$$\Leftrightarrow L(F_3 + F_4) - X_{CoG}(F_1 + F_2 + F_3 + F_4) = 0$$

CoG point along the body axis is calculated by formula below:

$$X_{CoG} = (F_1 + F_2) * \frac{L}{(F_1 + F_2 + F_3 + F_4)}$$

where: F_1, F_2, F_3, F_4 are forces collected from sensors.

2.2. Linear regression analysis

Linear regression method is a method of analyzing the relationship between the dependent variable Y (in our method, Y is the position of the CoG) with one or more dependent variables X (the body's measurements), based on a set of input observations [3]. In linear regression, the most concern is about uncertainty. The uncertainty can arise from three main sources: (i) measurement uncertainty, inaccuracy in observations, (ii) uncertainty of measurement model, non-effects linearity and (iii) the uncertainty of the time structure in the parameters of the linear model or the appearance of non-linear components. The general purpose of regression is to examize two things: (i) Does a set of predictor variables (X) do a good job in predicting an outcome (Y) variable? (ii) Which variables in the set X are significant in determining/ predicting the outcome?

Linear regression is often done to draw a model that can be used to make predictions about the future, and should therefore be designed to accommodate future "surprises" [3] . Those 'surprises' are structural changes in the system that arise from market changes, from technological innovations or from certain disagreements. By definition, nothing in historical data can reveal anything about future 'surprises'. According to Frank Knight's definition [4] - the first to clearly distinguish risks including known probability measures, and Knight called true uncertainty. A model is a group of unlimited nested events and no worst 'case'. Information gap models provide a clear and minimal representation of ignorance of future 'surprises'. Linear regression is essentially a regression analysis method of statistical probability.

In this paper, we used SPSS software to perform the algorithm with linear regression algorithm. To evaluate the model, it is necessary to pay attention to the following parameters:

1. Correlation coefficients R: is an index of measurement statistics showing how strong a relationship is between two variables.

2. Parameter R^2 (R-squared): reflects the degree of influence of the independent variables on the dependent variable. In other words, it reflects how close the data are to the fitted regression line.

3. Adjusted R-square: It is a modified version of R-squared, which has been adjusted for the number of predictors in the model. The adjusted R-squared increases only if the new term improves the model more than would be expected by chance.

4. Non-standardized regression coefficients (B): provide regression coefficients that reflect the change of the dependent variable accoeding to an independent variable.

5. Standardized regression coefficients (β): reflect the coefficients of independent variables on the dependent coefficients, which have been

standardized to remove constants. In all regression coefficients, which independent variables has the largest β, meaning that variable mostly affects to the change of the dependent variable. Therefore, when proposing a solution, much attention should be paid to factors that have a large β coefficient.

6. The variance inflation factor (*VIF*) coefficient: this value is used to check the phenomenon of multicollinearity. Multicollinearity is the phenomenon that independent variables have a strong correlation with each other. The regression model, which happens to be multicollinear, will cause many indicators to be misleading, resulting in quantitative analysis that no longer has much meaning. If $VIF < 10$, there is no multicollinearity phenomenon.

7. Error factor (Std. Error of the Estimate): is the error of the center of gravity calculated by formula and focus on trainning.

3. Proposed models

The purpose of the method is to determine the CoG point along the body's axis through body indicators. But the body has many indicators, each with a different relationship to the CoG of the body. Therefore, after the consideration process, assessing the relevance of different indicators decides to choose the close and easily defined indicators such as height, weight, three sizes of body's measurement. In this paper, we investigate three following relationships:

(i) Evaluate the CoG through height (h):

$X_{CoG} = f(h)$

(ii) Evaluate the CoG through height (h) and weight (w):

$X_{CoG} = f(h, w)$

(iii) Evaluate the CoG through height (h), weight (w) and three-ring measurements ($v1, v2, v3$):

$X_{CoG} = f(h, w, v1, v2, v3)$

in which

• X_{CoG} is the CoG point

• h is height

• w is weight

• $v1$, $v2$, and $v3$ are body's measurements (Chest, Waist and Hip)

In this process, we utilize the SPSS software tool to implement the linear regression algorithm to our obtained dataset.

4. Results and discusstion

After the data has been collected, the processing method is identified and the recommendations are made, we have conducted and obtained the following results.

Proposition 1: the dependency of CoG on the height (h)

The results obtained from SPSS are given as in the table 1. From table 1, we obtained the relationship between CoG and human's height:

$$X_{CoG} = h * 0.597 - 6.916 \quad (1)$$

Table 2 shows the summary of this model. To understand a linear regression model, the first concern is to consider the model's relevance to the data set through the R-square value. In Table 2, R-squared is 0.801, meaning that the independent variable (height) can explain 80.1% of the variation of the dependent variable (X_{CoG}), the remaining 19.9% is due to out-of-model variables and untrue random number. With the value of $VIF = 1.0$, the model does not show any multi-resonance phenomenon. Therefore, this model is completely valid and applicable.

The error factor value (Std. Error of the Estimate) is 1.772%, which is the error between the calculated value and the actual value taken and trained. That means that for a person who belongs to the training pattern when putting height parameters into formula (1), the maximum error will be:

$X_{CoG} * 1.7721517\%$ (cm).

Proposition 2: The dependency of CoG on height (h) and weight (w).

From table 3, we have the model of the CoG's dependency on weight and height as below:

$$X_{CoG} = h*0.585 + w*0.16 - 5.842 \quad (2)$$

Table 4 shows the summary of the model. The R-squared is 0.812 meaning that the independent variable (height and weight) can explain 81.2% of the dependent variable (X_{CoG}), the remaining 18.8% is due to variables outside the model and random errors. With the value of $VIF = 1.0$, the formula given does not show any multi-resonance phenomenon. Therefore, this tool is completely valid and applicable.

In table 4, the error factor value (Std. Error of the Estimate) is 1.736%, that is the error of the calculated value and the actual value taken and trained. That means that for a person who belongs to the training pattern when putting height parameters into formula (2), the maximum error will be:

$X_{CoG} * 1.7364978\%$ (cm).

Table 1.1. The dependency of CoG on height

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	*β*			Tolerance	*VIF*
(Constant)	-6.916	5.313		-1.302	0.196		
Height	0.597	0.032	0.895	18.796	0.000	1.000	1.000

Table 1.2. Model summary CoG - height

Model	*R*	*R* Square	Adjusted *R* Square	Std. Error of the Estimate
1	0.895	0.801	0.798	1.772

Table 1.3. The dependency of CoG on height and weight

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	*β*			Tolerance	*VIF*
(Constant)	-6.916	5.313		-1.302	0.196		
Height	0.597	0.032	0.895	18.796	0.000	1.000	1.000
Weight	0.016	0.025	0.038	0.640	0.524	0.634	1.577

Table 1.4. Model summary CoG – height and weight

Model	*R*	*R* Square	Adjusted *R* Square	Std. Error of the Estimate
2	0.901	0.812	0.808	1.736

Table 1.5. The dependency of CoG on height, weight and body measurements

Model	Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
	B	Std. Error	*β*			Tolerance	*VIF*
(Constant)	-19.112	8.696		-2.198	0.031		
Height	0.626	0.043	0.940	14.610	0.000	0.508	1.970
Weight	-0.097	0.067	-0.231	-1.444	0.153	0.082	12.228
v1	0.128	0.054	0.204	2.353	0.021	0.280	3.569
v2	0.054	0.053	0.106	1.010	0.316	0.192	5.201
v3	-0.020	0.043	-0.037	-.477	0.635	0.349	2.865

Table 1.6. Model summary CoG – height, weight and body measurements

Model	*R*	*R* Square	Adjusted *R* Square	Std. Error of the Estimate
3	0.909	0.826	0.815	1.7016853

Proposition 3: the dependency of CoG on height, weight and 3 sizes of body's measurement.

The formula relates the center of gravity (X_{CoG}) to the height (h), weight (w) and $v1$, $v2$, $v3$ (body's measurements)

$$X_{CoG} = h * 0.626 + w * (-0.097) + v1 * 0.128 + +v2 * 0.054 + v3 * (-0.020) - 19.112 \quad (3)$$

With the value of VIF = 1.0, the formula given does not show any multi-resonance phenomenon. Therefore, this tool is completely valid and applicable.

Similarly, in Table 6, R-square has a value of 0.826, meaning that the independent variable (height, weight and 3-ring measurements) can explain 82.6% of the variation of the dependent variable (focus), the remaining 17.4% is due to the variables outside the model and random errors.

The error factor value (Std. Error of the Estimate) is 1.701%, that is the error of the calculated value and the actual value taken and trained. That means that for a person who belongs to the training pattern when putting height parameters into formula (3), the maximum error will be:

X_{CoG} * 1.7016853% (cm).

Given the above three equations, we can estimate the position of the CoG based on height, weight and 3-ring body measurements. Depending on which data is available, we can choose each of the above three models. Definitely, the third model with more explanatory variables gives the least error between the predicted and the actual value. If we have only height or weight, or both, the results are still valid with an acceptable R-squared and errors. In other words, based on the measurements of the body, we can estimate the balance status of the human, which is based on CoG.

5. Conclusion

In this paper, we proposed three models which can estimate/predict the position of human's Center of Gravity (CoG) based on physical measurements of the body. The proposed model is at low cost but effective. The errors in three models are approximately 1.7%, which is quite good. Based on which source of data is available, we can choose suitable model to estimate the position of the CoG. From there, these models help doctors in disbalance order diagnosis.

Acknowledgments

This research is funded by the Hanoi University of Science and Technology (HUST) under project number T2017-PC-111.

The authors also want to express our sincere thanks to all doctors, nurses and patients in Inpatient Department of Traditional Medicine, Ministry of Public Security (No. 278 Luong The Vinh, Trung Van, Tu Liem, Hanoi), and many students in HUST to help us test the system.

References

[1] S W Wen and C D Naylor, Diagnostic accuracy and short-term surgical outcomes in cases of suspected acute appendicitis, 1995 May 15; 152(10): 1617–1626.

[2] Rahman, N. M., Singanayagam, A., Davies, H. E., Wrightson, J. M., Mishra, E. K., Lee, Y. C. G., … Gleeson, F. V. (2010). Diagnostic accuracy, safety and utilisation of respiratory physician-delivered thoracic ultrasound. Thorax, 65(5), 449–453.

[3] D. Nc, AN INFO-GAP APPROACH TO LINEAR REGRESSION Faculty of Mechanical Engineering Technion — Israel Institute of Technology Haifa 32000 Israel Center for Neuro-engineering, no. 2, pp. 800–803, 2006.

[4] G. P. Watkins and F. H. Knight, Risk Uncertainty and Profit Knight, Q. J. Econ., vol. 36, no. 4, p. 682, 1922.