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A Design on Center-of-Mass Measuring Device

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Abstract: ***Determining the position of the body Center of Mass (CoM) is played a very important role in the analysis of movement and ability to balance human. The Center of Mass of human is a theoretical point which the position can change constantly when moving. The position of the body Center of Mass is also depended on the age, the gender, property of bones and muscles, etc. Nowadays, in order to determine the Center of Mass of human, there are quite a lot of measurement methods in the world. However, these methods are generally very expensive, take a lot of time to measure, complicated implementation process and specially, no research has been done on Vietnamese people. Therefore, in order to optimize the above methods and meet the requirements of suitable for Vietnamese 's body, we have designed a system that can find the body Center of Mass.***

Keywords: Center of Mass (CoM), Vestibular, Vestibular Disorders**.**

1. Introduction

The body Center of Mass is played a very important role in applications of many different fields, such as sports [1], medicine [2], etc. In sports, to study the postures, movements of athletes, the focus is very important to make standard moves. In some people with defective body, or some diseases related to body imbalance, such as ischemia, or vestibular disorders, body of Center of Mass deviation can cause difficulties in movement and life [3]. Such as imbalance and disorientation (not stable, difficult to walk) can make the patients had accident or prolonged trauma, created a burden for families and society. So, accurate diagnosis of degree of body imbalance (especially for vestibular disorder patients) is an essential requirement in treating, however, the current reality in Viet Nam is a lack of device to support the diagnosis of body imbalance. Experts often diagnose based on personal experience through clinical examination. Therefore, the research of building a model to determine the body Center of Mass to measure the state of imbalance of body will bring great benefits in public health care, such as:

- Support in training, research and development of the new method and treatment in sports.
- Support doctors in process of diagnosing the degree of patient 's imbalance to be able to provide a more proper treatment regimen.
- Support the process of training and treatment.
- Serve the research, train and develop of medicine, create a premise for depth research in the clinical field.
- In the world, there are many published researches on measuring Center of Mass of human body. These methods are:
- Measuring Center of Mass by using Body Segments analysis [4][5][6].
- Real time estimation and Tracking of human body Center of Mass by using 2D Video Imaging [7].
- Body segment parameters estimation using 3D photogrammetry [8].
- Measuring Center of Pressure by using a Reaction Board [9].

Center of Mass of human 's Body Segment is a method done by modeling the main parts of the body into blocks. To calculate the focus of the human body, firstly, one will calculate the focus of each block corresponds to each part of the body. Then, sum up to find the focus of the human body. The measurement process of this method is complex, however, it allows to determine focus of human body in the dynamic state.

In the method of using 2D video imaging, one will analyze the 2D image of subject to give the body focus. This method uses the captured image of the subject and analyzes the image into the silhouette, while performing a diagnosis of the bone structure of the body. Finally, analyze each structural block and handle it with the Delaunay method to give the body focus. The advantage of this method is flexible, able to determine center of human in the dynamic state, however, this method is very expensive, takes a long time to determine and limited accuracy. Besides, because it simulates the structure of the body, so there are some cases that bone structure of objects is different than simulations, causes differences in the results.

In the method of estimating body segment parameters using 3D photogrammetry, one will be based on 3D imaging by using multiple cameras to simulate body segmentation parameters of subject. A body scanner was made with multiple cameras and 3D point cloud data generated using structure form motion photogrammetry reconstruction algorithms. The point cloud was manually separated into body segments, and convex hulling applied to each segment to produce the required geometric outlines. This method has quite high accuracy, however, the disadvantages of this method are very complicated, costly.

In the method of using Reaction Board, one uses a long flat board which has 4 bases attracted with 1 sensor on each base. When measurement, one person will lie on board, system will collect data from 4 sensor (2 sensors are located in shoulder and 2 ones in legs) and calculate the position of center of body. Although, the system shows the exactly static position of center of body, this method needs the dynamic position of center of center of body human.

In general, to assess the body's focus, there are many different methods can be used, however, these methods are very expensive, time-consuming to measure, low accuracy, complex implementation process. Therefore, the requirement must build an optimized system, utilizes the advantages of previous studies and while overcoming the disadvantages of those systems, and apply reality in Viet Nam.

The paper is organized as follow. Section 2 presents the design of system. Section 3 describes the calibration of system and measurement to evaluate the system. Section 4 concludes the paper.

2. Design system

2.1. Methodology

With advantages and disadvantage of the methods outlined above, we have designed a model that determines the body Center of Mass through some body indicators, such as height, weight. To compare the results to evaluate the accuracy of the method, we designed a system to determine the body's focus. These body focus parameters are used as sampling parameters to find the formula for calculating the focus through body parameters. The construction model will have to meet the following factors:

- The system is not costly, easy to move.
- The focus determination process is made simply.
- The focus determine model needs high accuracy.
- The system works stably for a long time.
- Build a clear and realistic database.

From the obtained database, can support more in-depth studies to build a quick, stable and accuracy formula.

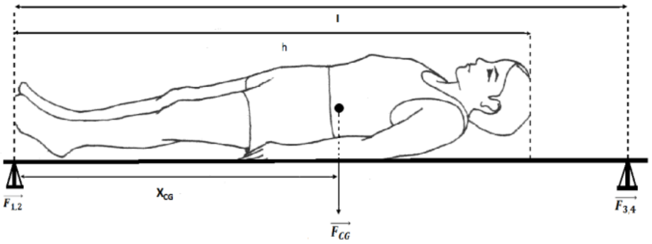

Figure 1: The proposed model

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. The subject will be guided to the correct position and relaxed body when lying on the system. After that, the data collection system will receive signals from loadcells. Through $\overrightarrow{F_{12}}$ and $\overrightarrow{F_{34}}$ to calculate the position of $\overrightarrow{F_{CG}}$ as X_{CG}, with $\overrightarrow{F_{12}}$ is total force of loadcell 1 and loadcell 2 in "foot part", $\overrightarrow{F_{34}}$ is total force of loadcell 3 and loadcell 4 in "head part". In the figure 1, *l* is the length of system and *h* is the height of subject.

From the above proposed system, we designed a system which consists of 2 parts: Mechanical part and data collection part. Mechanical part is a rectangular iron frame with predetermined size. It has a clear section to set foot and a plane part to lie. At the 4 legs of the frame, we attach 4 sensors so that the contact points between the frame and sensor is vertical. When collecting data, we divide the data obtained from the sensors into 2 separate parts: "head part" and "foot part". "head part" is sum data of 2 sensors mounted on the frame in contact with the head of measuring object. Similar with 2 sensors in the "foot part". Data collection part is a system to process data obtained from 4 sensors. Firstly, the system will execute calibration system to 0. Then, it will conduct data acquisition, calculate the focal point and display the screen coordinates of this point.

2.2 Design device

The Center of Mass (CoM) is defined as the body's balance point which the sum of the moments rotates to 0. Based on the balance principle of 2 parallel forces in the same direction:

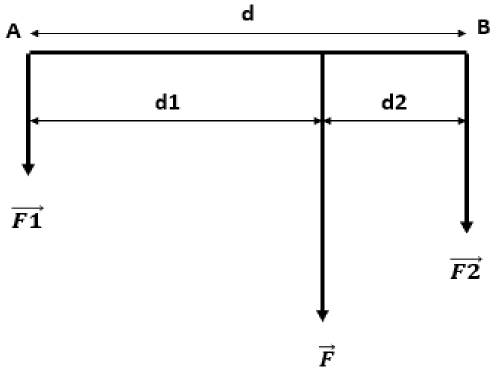

Figure 2: 2 parallel forces in the same direction

We have:

$$F1.d1 = F2.d2$$
$$\Leftrightarrow F1.d1 = F2\,(\,d - d1\,)$$
$$\Leftrightarrow (\,F1 + F2\,)\,.d1 = F2.d$$
$$\Leftrightarrow d1 = \frac{F2}{(\,F1 + F2\,)}\,.d$$

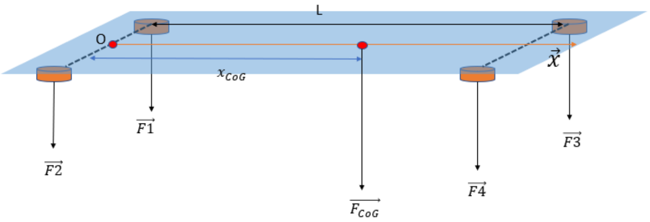

Figure 3: Location of CoG and forces

CoP is calculated by formula below:

$$X_{CoG} = (F1 + F2) * \frac{L}{sum}$$
$$sum = F1 + F2 + F3 + F4$$

Where: $F1, F2, F3, F4$ are forces collected from sensors.

L is frame length (*L* = 1475 mm).

X_{CoG} is the coordinates of CoG point fromfoot.

***a. Mechanical design*:**

In order to meet the above requirements, we have designed the following:

Figure 4: Design of side mechanical system

Figure 5: The complete design (Upper face)

Figure 6: The complete design (Lower face)

b. Electrical Design

Block diagram

The block diagram below explains how our device work:

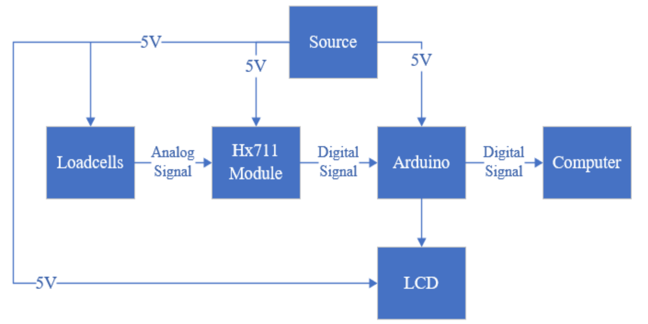

Figure 7: The block diagram.

Analog signal that collected from sensors will be transform to digital signal through Hx711 module. The Hx711 module send the data to the microcontroller, then the microcontroller will calculate and display the screen. All blocks are supplied by a 5V power source.

<u>About Loadcell:</u>

Concept: is a type of force sensor, used in measuring weight, mass.

Function: convert force, mass into electric signal (analog signal).

Structure: 2 parts

- Strain gauge: acts as a variable resistor.
- Load: bearing metal part.

Principle: Use the principle of Wheatstone bridge circuit, for 3-pin loadcell, it is required to combine 1 another loadcell or 1 resistor to create a complete bridge circuit. The force value varies by the electrical difference between the sensors.

<u>About module HX711</u>

HX711 is the amplifier and signal converter circuit that converts analog signal into digital signal with 24-bit resolution.

Because the loadcell's output has very low voltage, about 1-5mV. Therefore, high resolution ADCs are needed to be able to read the above mV voltage level.

The Hx711 control library is clearly and fully supported on Arduino.

<u>About kit Arduino</u>

Role of Kit Arduino:

- Communicating between computer and HX711.
- Processing all signals sent from HX711.
- 5V supply for HX711 and loadcell.

Connecting the system:

To receive signal from sensor, we implement steps below:

- Assembling circuits according to the principle diagram:

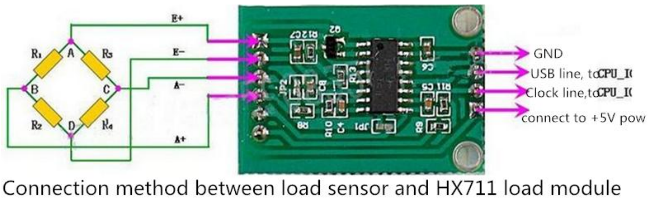

Figure 8: Connection method between sensor and Hx711 module

- Combined with 2 resistors with a value of 1kΩ to make a balanced bridge circuit and create voltage difference. Loadcell operates under 5V voltage.
- Using Hx711 library and writing code to calculate, display measured results from loadcell on computer screen and LCD 16x2 screen.

3. Calibration

3.1. Loadcell calibration

After installing the circuit and loading the code, the result displayed is incorrect. The signal from the loadcell after passing the ADC will display a number in the range of 224, that number will not match the actual weight, so we need to find the formula to relate that number to the actual weight, while checking the loadcell's linearity.

The calibration system includes of 2 iron bar, 2 pair of bolts and screws, 1 mechanical scale, 1 MICA surface, and loadcell needs calibration.

- Install the system as shown:

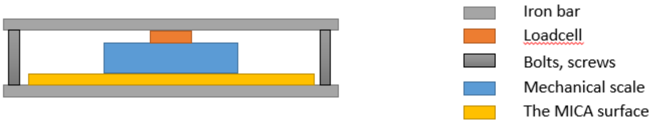

Figure 9: Calibration loadcell model

- Screw the screws at the ends of the iron rod to fix the force, twist and stop when the scale is only at 5kg, 10kg, 15kg, 20kg .
- For each weight level, record the results in the Excel table
- Repeat the above steps 3 to 5 times

- From the data table obtained, draw a graph and calculate the corresponding correction factor for each loadcell.

3.2. Systemcalibration

After calibrating each individual loadcell, install the loadcell into the system, then implement system calibration. Because of system after installation, loadcell and its leg are not aligned, the iron frame is not square, the system is not on a flat surface. So we check and calibrate system. To ensure flexibility for the mechanical system, parts of iron frame are connected by bolts and screws, so we check the flatness of the system by the water ruler. In combination with adjusting code of the data collection system, so that the value displayed when no effect force will be 0.

3.3 Evaluate the accuracy of the system

After completing calibration system, we will evaluate the accuracy of system. We will use heavy objects with a small force contact point, effect force on each specific position of the mechanical system. Then, recording the obtained results at the data collection system to evaluate the error.

Figure 10: The heavy object to evaluate

Do the following steps:

- Install 4 Loadcell (calibrated) on the system.
- Check the flatness of the scale by the water ruler.
- Use heavy above objects to check the measured total value.
- Apply force at each point to calculate the coordinates at X at the point of action.
- Data processing and evaluation of error.

Based on the results obtained, there are errors in the measurement process, errors of weight are from 0.09% - 15%, errors of position effect force is 0.08 % – 7.69%. For errors of position, because the measuring object has a height between 140 centimeter and 170 centimeter, so the center of body is from 70 centimeter to 85 centimeter (in the middle vertically the body). The errors in this range is from 0.5% to 1.5%, that is quite low and can accept. For errors of weight, because weight of the heavy object is quite small, the effect force on each loadcell is quite small (about 5Kg) which made high errors. Therefore, we used an object with bigger weight. Because we cannot find an object like the heavy above object, we decided to use a person whom weight is 51 Kg. With request is the small force contact point to evaluate of the system, however, for object like people, the small contact point is very difficult. Therefore, we have proposed a method that: Using a square iron which size is 20x20 milimeter, to make contact point, then the person will stand on the iron bar to create the effect force. The iron bar will be placed parallel to horizontal of the system to minimize deviation of position. Because the width of iron bar is 20 milimeter, to determine the specific position when effect force, we do the followwing: For example, we determine position at 100 milimeter, the position of iron bar is in the range of 90 milimeter to 110 milimeter.

Figure 11: The iron bar is used to evaluate system.

The steps are the same as when using heavy objects.

Table 2 present the results obtained when measuring the peoples. Based on the results obtained, there are errors in the measurement process, errors of weight are from 0.1% - 3.5%, errors of position effect force is 0.03 % – 1.35%. These errors are very small and can accept in this case. This result is completely consistent with the measuring object in both height and weight

4. Conclusion

With the requirements mentioned above, we designed a system which can determine Center of Mass of human body with high accuracy, simple implementation process, stable, not costly, flexible, easy to move. And specially, this research is done on Vietnamese people. Although there are errors in the measurement process, these errors are very small and can accept in this case. The cause of errors may come from external causes, such as iron frame, loadcell contact point, weight frame surface. We can completely optimize it to serve for more in-depth research.

Table 1: Results obtained when evaluate by the heavy object.

Reality	**First time**				**Second time**			
	Location displayed	**Error (%)**	**Weight obtained**	**Error (%)**	**Location displayed**	**Error (%)**	**Weight obtained**	**Error (%)**
0	0.254		11.45	**6.02**	0		10.87	**0.65**
10	9.118	**8.82**	11.67	**8.06**	9.64	**3.6**	11.27	**4.35**
20	18.746	**6.27**	11.36	**5.19**	18.696	**6.52**	11.18	**3.52**
30	28.06	**6.46**	11.58	**7.22**	28.866	**3.78**	11.61	**7.5**
40	39.124	**2.19**	11.76	**8.89**	38.576	**3.56**	11.49	**6.39**
50	48.842	**2.31**	11.858	**9.80**	50.706	**1.41**	11.36	**5.19**
60	60.2	**0.33**	11.54	**6.85**	60.668	**1.11**	10.79	**0.09**
70	69.03	**1.38**	11.33	**4.91**	70.772	**1.1**	10.85	**0.46**
80	79.31	**0.86**	11.31	**4.72**	81.6	**2**	10.82	**0.19**
90	89.492	**0.56**	11.35	**5.09**	91.4	**1.55**	10.96	**1.48**
100	100.522	**0.52**	11.11	**2.87**	101.678	**1.67**	11.41	**5.65**
110	110.68	**0.61**	11.118	**2.94**	109.88	**0.1**	11.51	**6.57**
120	120.404	**0.33**	11.84	**9.63**	121.584	**1.32**	11.59	**7.31**
130	130.994	**0.76**	11.18	**3.52**	131.874	**1.44**	10.89	**0.83**
140	140.164	**0.11**	11.26	**4.26**	141.87	**1.33**	11.14	**3.15**
147.5	144,9	**0.06**	10.9	**0.93**	145,5	**0.34**	11	**1.85**

Table 2: Results obtained when measuring people

Reality	**First time**				**Second time**			
	Location displayed	**Error (%)**	**Weight obtained**	**Error (%)**	**Location displayed**	**Error (%)**	**Weight obtained**	**Error (%)**
0	0.55		51.06	**0.12**	0.44		51.86	**1.69**
10	10.28	**2.8**	50.4	**1.18**	10.23	**2.3**	52.01	**1.98**
20	19.84	**0.8**	50.84	**0.31**	20.71	**3.55**	52.15	**2.25**
30	30.59	**1.97**	50.88	**0.24**	30.37	**1.23**	51.83	**1.63**
40	40.36	**0.9**	50.84	**0.31**	40.13	**0.33**	52.62	**3.18**
50	50.04	**0.08**	50.27	**1.43**	50.5	**1**	52.55	**3.04**
60	60.02	**0.03**	50.56	**0.86**	60.43	**0.72**	52.3	**2.55**
70	70.02	**0.03**	50.77	**0.45**	70.57	**0.81**	52.7	**3.33**
80	80.44	**0.55**	50.88	**0.24**	80.56	**0.7**	52.47	**2.88**
90	90.53	**0.59**	50.89	**0.22**	90.98	**1.09**	52.25	**2.45**
100	100.44	**0.44**	50.66	**0.67**	100.4	**0.4**	52.5	**2.94**
110	110.86	**0.78**	50.96	**0.08**	111.4	**1.27**	51.97	**1.9**
120	121.62	**1.35**	50.73	**0.53**	121.69	**1.41**	52.68	**3.29**
130	131.7	**1.31**	50.78	**0.43**	131.49	**1.15**	52.22	**2.39**
140	141.22	**0.87**	50.87	**0.25**	141.66	**1.19**	52.27	**2.49**
147.5	146.7	**0.54**	51.84	**1.65**	146.6	**0.61**	52.34	**2.63**

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