Detection of Similarity of Trajectory of Center of Gravity in Operating Unicycle Uses Motion Capture System

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Abstract

Riding a unicycle is good exercise to enhance and keep rider's sense of equilibrium, reflexes and quickness. But a lot of people can not ride a unicycle because its unstability. And there are no theoretically to be able to ride a unicycle. A way to do so is that, at first, the model of riding unicycle is simply considered as the cart-pendulum model, then using inputs and outputs obtained by measured data of Motion Capture System(MCS), its controller is able to derived. But a relationship between rider's body manipulations and movements of center of gravity are not unique. because there a lot of way to make same trajectory of center of gravity by different body manipulations. Therefore, in this paper, to understand a way to ride a unicycle by the relationship, a way to decide the similarity of movements of center of gravity is described.

1. Introduction

Riding a unicycle is good exercise for forge the sense of equilibrium, reflexes and alterness. But, to ride unicycle is problem while the poor operator. For example, keep riding a unicycle is very difficult, a lot of time is necessary until the skill is acquired, and high danger. Dynamic unicycle simulator is developed to solve such a problem [1]. Supporting to grow human skill of a unicycle is necessary that way to operate machine of seniors is measured and analyzed. Chiefly, sensor in dynamic unicycle simulator obtain human input by unicycle until now. For example, using BPMS(Body Pressure Measurement System) is set up in the saddle, declared the difference between seniors and beginners from the relation of CP(Center of Pressure) of BPMS and MBP(Moment Balancing Point) that denies rotation moment of saddle[2]. But, the analysis by this method is not clear different of operation in seniors. Thus, we are requested analysis about different of operation of seniors in riding unicycle.

Thus, in this study, we aim analysis about trajectory of center of gravity of each seniors in unicycle operation using MCS(Motion Capture System), and final purpose that is clear different of operation in seniors. When operating unicycle, even in the same trajectory of center of gravity, way to move of the body is exist variously. Then, we analyze way to select movement of the body in seniors, and move center of gravity. Therefore, to derive same trajectory of center of gravity by way to move a different body is necessary. Therefore, in this paper, we divide similar operation of the center of gravity movement in riding unicycle for dividing same trajectory of center of gravity by way to move a different body. We divide center of gravity from obtained data by using MCS(Motion Capture System) for measurement coordinates position of each segment in human. Moreover, divide movement from velocity information of center of gravity, and calculate similarity of dividing center of gravity data.

2. Environment of experiment

When we measure data of unicycle beginner's, safety is not secured. Moreover, there is a fault that can't measure for a long time. To improve it, we use Unicycle simulator developed by Kinoshita et al. Unicycle simulator is shown in fig1. Moreover, MCS is used to obtain the location information of operator. MCS used eight cameras. Camera measures the markers of each part of the body, and we can ob-

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tain the information of location in three dimensions. A camera is shown in fig2,location of camera is shown in fig3,and performance of camera is shown in Table 1.

3. Derivation of center of gravity

In this study, we are using the MCS for analysis of human movement on unicycle operation. Analysis of fullbody motion is difficult reason for a lot of measurement point. And so, we analyze that focus on center of gravity is affected by fullbody. Thus, in this chapter, we derives center of gravity that is important elements in analysis of unicycle operation.

However, MCS can obtain only position information of marker. Thus, we need to derive center of gravity from position information of marker. Flow of derivation is shown in below.

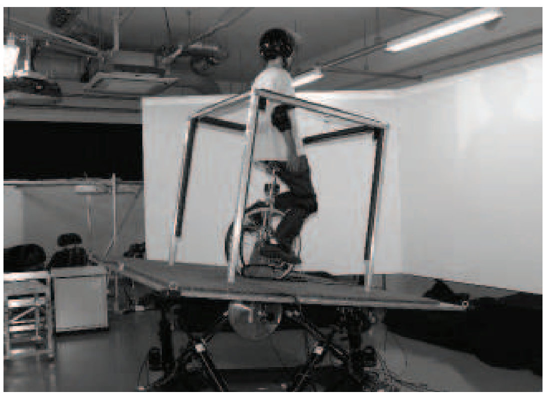

Figure 1. Unicycle simulator

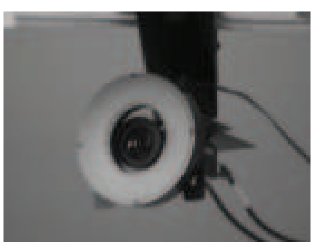

Figure 2. Camera used

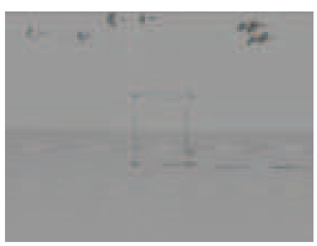

Figure 3. position of Camera

Table 1. Performance of camera

Monochrome	$8\,[bit]$
Resolution	640×480
Charge Coupled Device	$\frac{1}{2} typeCCD$
Element Model	$9.9\,[\mu m] \times 9.9\,[\mu m]$
Frame Rate	$60\,[fps]$
Lens Mount	C mount
Camera Size	$29[mm] \times 44\,[mm] \times 67\,[mm]$

- At first, the marker is installed on the position shown in fig4.
- Each segment on center of gravity and mass is calculated from marker position.
- The center of gravity is synthesized by using center of gravity on each segment and mass. The method is shown in fig 5.

3.1. Method of derivation center of gravity

To derive center of gravity in body, at first, derives center of gravity on each segment such as head, body, and arm. Adjoined segment of center of gravity is synthesized from these center of gravity. Center of gravity in fullbody can derive by repeating it. Method of derivation center of gravity is shown in fig 5.

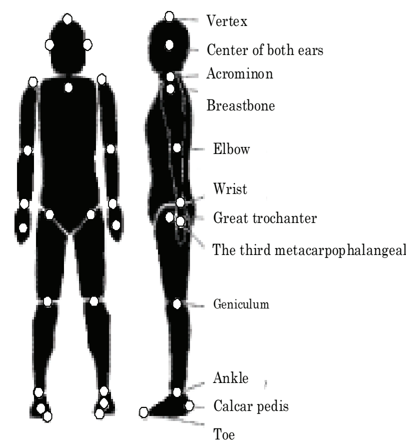

Figure 4. Installation position of Marker

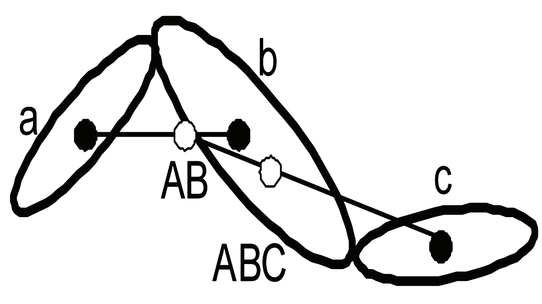

Figure 5. Compound center of grabity

In fig 5, at first, derive center of gravity of a and b. Next, derive AB that is dividing point of a and b. Furthermore, synthesize center of gravity of AB and c, and ABC is calculated by three segments of synthetic center of gravity, Derivation of equation of center of gravity is shown below.

$$X_{CG} = \frac{\sum_{i=1}^{n} x_i m_i}{\sum_{i=1}^{n} m_i} \quad (1)$$

$$Y_{CG} = \frac{\sum_{i=1}^{n} y_i m_i}{\sum_{i=1}^{n} m_i} \quad (2)$$

$$Z_{CG} = \frac{\sum_{i=1}^{n} z_i m_i}{\sum_{i=1}^{n} m_i} \quad (3)$$

(x_i,y_i,z_i:Center of gravity of each segment, m_i:Mass of each segment)

Center of gravity is balance point of mass $\times$ length of arm in the left side and the right side of fulcrum. Thus, derivation of center of gravity becomes possible only center of gravity and mass of each segment shown by equation (1), (2), (3). Then, center of gravity and mass of each segment is needed[3].

3.2. Calculation of center of gravity in each segment

Center of gravity in each segment can be derived by coordinate position in each marker measured by MCS and the following equation.

$$CGHead = (1 - 0.6633) \times Vertex + 0.6633 \times Ear \quad (4)$$

$$CGTrunk = (1 - 0.5216) \times Ear + 0.5216 \times ((RightGreattrochanter + LeftGreattrochanter)/2.0) \quad (5)$$

$$CGUpperarm = (1 - 0.50606) \times Breastbone + 0.50606 \times Elbow \quad (6)$$

$$CGForearm = (1 - 0.41666) \times Elbow + 0.41666 \times Wrist \quad (7)$$

$$CGHand = (1 - 0.515) \times Wrist + 0.515 \times Thethirdmetacarpophalangeal \quad (8)$$

$$CGThigh = (1 - 0.39833) \times Greattrochanter + 0.39833 \times Geniculum \quad (9)$$

$$CGShank = (1 - 0.41333) \times Geniculum + 0.41333 \times Ankle \quad (10)$$

$$CGFoot = ((1 - 0.56) \times Calcarpedis + 0.56 \times Toe) \times 0.5 + Ankle \times 0.5 \quad (11)$$

3.3. Calculation of mass in each segment

Calculation of mass in each segment can be derived by weight of operator and the following equation.

$$WHead = 1.9074 + 0.0319 \times BW \quad (12)$$

$$WTrunk = -0.7076 + 0.5324 \times BW \quad (13)$$

$$WUpperarm = 0.4852 + 0.0215 \times BW \quad (14)$$

$$WForearm = 0.2477 + 0.0129 \times BW \quad (15)$$

$$WHand = 0.0759 + 0.0045 \times BW \quad (16)$$

$$WThigh = -1.5112 + 0.1271 \times BW \quad (17)$$

$$WShank = -0.1792 + 0.0437 \times BW \quad (18)$$

$$WFoot = 0.2529 + 0.0089 \times BW \quad (19)$$

(BW:Body Weight[kg])

3.4. Result of derivation in center of gravity

To evaluate center of gravity, compare using BPMS that can measures the center of pressure on plane. Compared result is shown in fig 6, fig7

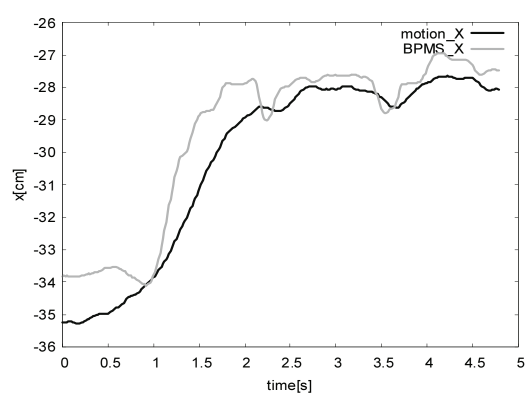

Figure 6. calculated result of COG X

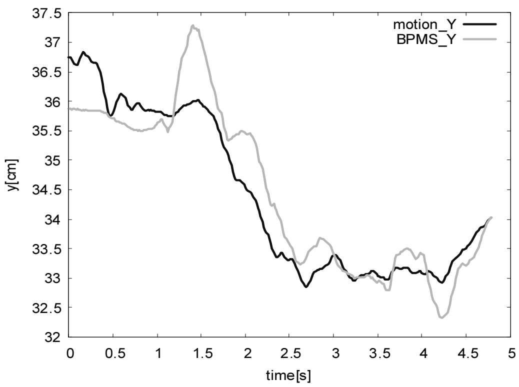

Figure 7. calculated result of COG Y

4. Division of data in center of gravity

Movement has the process that increases the velocity from the geostationary state, decreases the velocity in a certain point, and become the geostationary state. Focus on this change of state, and divide data of center of gravity [4][5][6]. That is, derive velocity of three dimension data of center of gravity, and the point in acceleration becomes 0 is candidate of division point. Result of detects in division point is shown fig8.

4.1. deletion of false detection in division point

In the case of false detection in division point, take out the first three points of division point, and it named F, M, L in order taking out. That is shown in fig9. Also, black point of fig9 is shown the candidate of division point. Method of deletion in false detection of division point is shown below.

- At first, detect a point d_1 that is furthest point from F

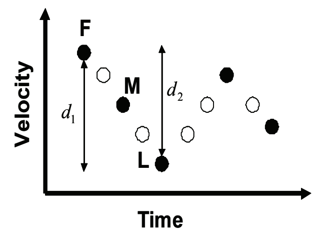

Figure 9. Camera used

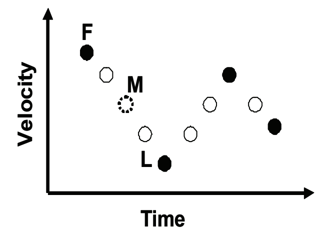

Figure 10. position of Camera

in three points taken out.

- Next, detect a point d_2 that is furthest point from L in three points taken out.
- When the distance between F from M is not furthest point and the distance between L from M is not furthest point, M is deleted from candidate of division point.

In the fig.9, L is furthest point from F.. Thus, becomes $d_1 = FtoL$. Also, F is furthest point from L.Thus, becomes $d_2 = LtoF$. The distance between F from M is $MtoF$, and the distance between L from M is $MtoL$. thus $MtoF \neq d_1$, $MtoL \neq d_2$.Thus, M is deletion from candidate of division point in fig. 9,and, division point is becomes as shown in fig.10. False detection in division point of figure is deleted. And the result is shown fig.11.

4.2. Result of division in data of center of gravity

Show in fig.11, divide movement from velocity of center of gravity. From the result, derive division time of move-

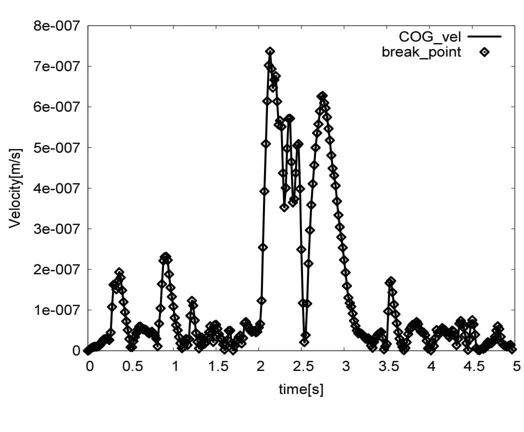

Figure 8. false detection of COG velocity

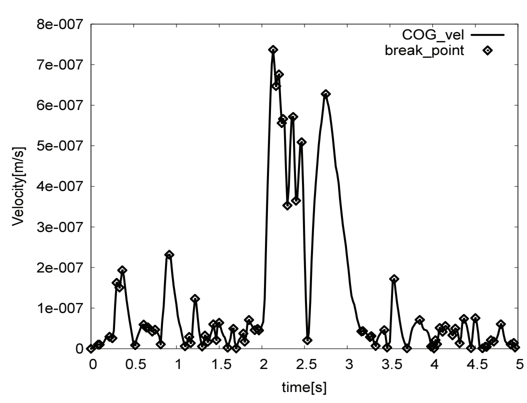

Figure 11. detection of division point in COG

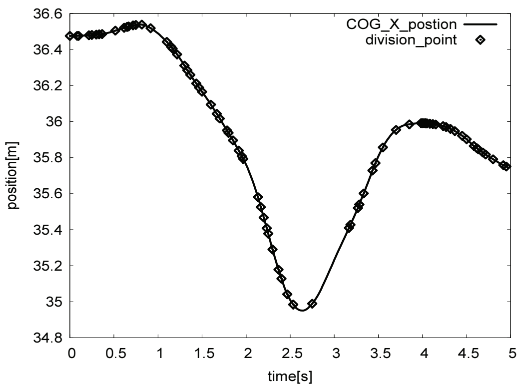

Figure 12. divisoion point of positon in COG X

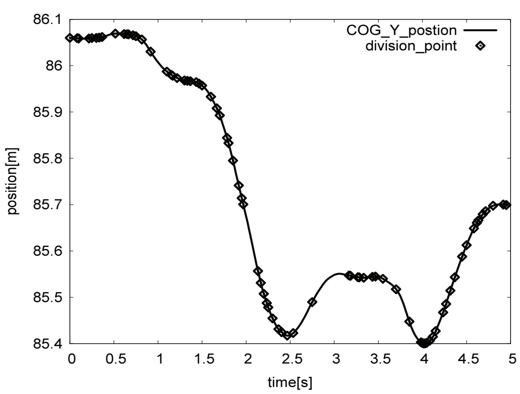

Figure 13. divisoion point of positon in COG Y

ment, and divide movement of center of gravity in three dimensions. Result of movement division about X axis, Y axis and Z axis is shown fig.12, fig.13 and fig.14.

5. Detection of similar data by Dynamic Time Warping

We use DTW(Dynamic Time Warping) to derive similarity of division movement [7],[8],[9],[10].DTW is a method to derive distance of two different data. When distance of two data is near, similarity is high, and when distance of two data is large, similarity is low. The data of movement A and B is shown equation (20) and (21).

$$A = a_1, ..., a_i, ...a_M a_i = (X_a i, Y_a i, Z_a i) \quad (20)$$

$$B = b_1, ..., b_j, ...b_N b_j = (X_b j, Y_b j Z_b j) \quad (21)$$

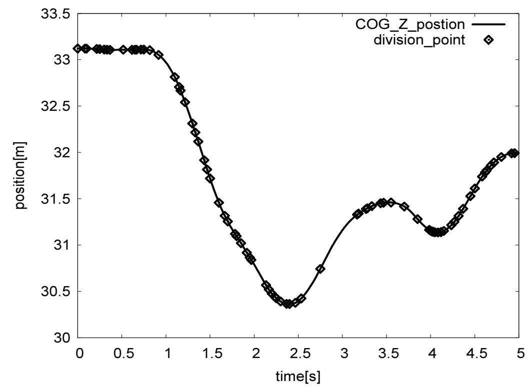

Figure 14. divisoion point of positon in COG Z

At this time, distance between data A and B is shown equation (22).

$$d_{i,j} = \sqrt{(X_a i - X_b j)^2 + (T_a i - Y_b j)^2 + (Z_a i - Z_b j)^2} \quad (22)$$

$$S_{i,j} = d_{i,j} + min(S_{i,j-1}, S_{i-1,j-1}, S_{i-1,j}) \quad (23)$$

$$d_{1,1} = S_{1,1} \quad (24)$$

$$D(A,B) = \sum_{i=1,j=1}^{M,N} S_{M,N} \quad (25)$$

In above method, derive similarity from distance of two different data.

5.1. Derivation of threshold

Derive threshold to decide similarity of data. As way to derivation, using MCS, and similar movements is measured in some times. Movement data of similarity is calculated by DTW. And this result is threshold. But, the number of each divided data might is different. Threshold suitable for number of data is necessary. Thus, threshold to determine similarity is shown in equation (26).

$$Threshold = 1.873 \times max(i,j) \quad (26)$$

5.2. Result of detection in similarity data

In the fig.12,fig.13,fig.14, in order of data string in between a division point and next division point named $Data1, Data2, Data3, ..., Data60$. Using the equation (22),(23),(24) and (25), Similarity of each data row was detected. Result is shown in table2. "Class" in table2 is shown similarity data of class, and "Data" is shown each elements of data string in between a division point and next division point.

6. Conclusions

We derived center of gravity of the body riding unicycle. Moreover, we divided movement from velocity information of center of gravity, and calculate similarity of center of gravity data. In this study, the final purpose is analysis about way to select movement of the body in seniors, and move center of gravity. Therefore, movement becomes clear in similarity data of class derived by DTW in future. Moreover, way to select optimal center of gravity movement of senior is analyzed using class of trajectory of center of gravity.

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Table 2. Class of similar data

Class	Data
1	1, 3, 10, 19, 34, 39, 40, 42, 47, 54, 58, 59
2	2, 20
3	4, 9
4	6, 43
5	8, 11, 12, 16, 17, 24, 26, 45, 48, 53, 57
6	14, 18, 21, 22, 23, 25, 30, 32, 41, 44, 50, 56
7	15, 31, 35, 36, 37, 52
8	27, 33
9	29, 38, 49, 51, 60