A study on statistical human joint models with application to the long-distance running.

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Abstracts

We study the problem of modeling and analyzing the human movement data. A study on the human movement is very important roles in the fields of sports/health management, physical therapy, robotics and any other research. Most effective measurement instrument for the human movement analysis is motion capture system. Motion capture system is able to observe the precise measurements of spatial locations. In the sports analysis, it requires to seek the optimal movements (e.g. running speed, steady movement, minimize the fatigue etc...) based on the athletes individuality. However, previous researches, based on the motion capture systems, were only focused on general optimal movement, it does not based on the athlete's movement individuality. In this research, we propose the optimal movement estimation method based on the human joint model using motion capture system's 3-dimensional coordinate data. Finally, we apply our proposed method to the long-distance running form analysis, focusing on the athlete's movement individuality.

Keywords: human joint model, sports analysis, long-distance running analysis, motion capture system

1. Introduction

In this article, we discuss the long-distance running analysis based on the motion capture system. Human movement analysis based on the motion capture system is able to analyze the mathematical kinematic characteristics using the human body model. For instance, in the medical research area, researchers are analyzing Alzheimer disease, infantile paralysis and any other diseases using a motion capture system (Perry, 1992; Whittle 2002; Kirtley, 2006). On the other hand, sports analysis is difficult use a motion capture system, because many of sports needed large experimental circumstance. Therefore, sports analysis is mainly using video analysis software (e.g. Dartfish^{TM}, Contemplas^{TM}, Silicon Coach^{TM}) with a standpoint of physical therapy approach. Some researchers are using a motion capture system, but their researches are focused on the "running motion" itself. It does not based on the athlete's movement individuality.

On the other hand, from the standpoint of statistics, Olshen *et al.* (1989) proposed the bootstrap estimation for confidence intervals of the functional data with application to the gait cycle data observed by the motion capture system. Rice and Silverman (1991) and Grambsch *et al.* (1995) discussed functional data analysis of the human hip joint based on the motion capture system. Faraway *et al.* (2007) proposed 3-dimensional model of the human arm using Bzier curve based on the motion capture system. However, these approaches do not focus on the athlete's movement individuality like a sports analysis approach.

In this research, we propose the optimal movement estimation method based on the human joint model using motion capture system's 3-dimensional coordinate data. Finally, we apply our proposed method to the long-distance running form analysis, focusing on the athlete's movement individuality.

The organization of the rest of the paper is as follows. In Section 2, we describe our motion capture system's datasets. In Section 3, we discuss the optimized movement based on the motion capture system's data. We conclude with a summary in Section 4.

2. Dataset

In this section, we describe our motion capture system's datasets. We use four subjects of the professional long distance runner athletes. In the experimental situation, we set the 42-markers on the subject's body (Figure 1), and we capture these markers using motion capture system Vicon^{TM}.

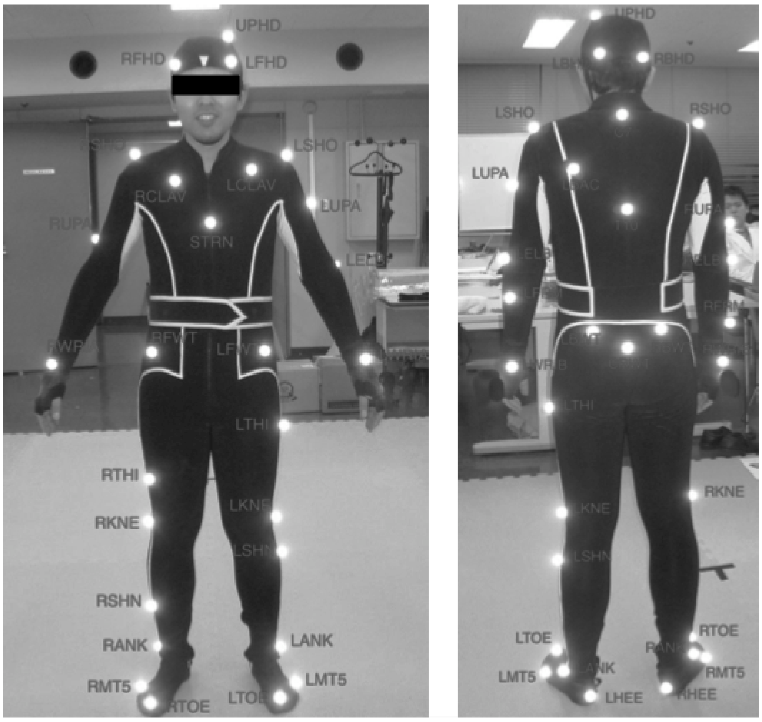

Figure 1: Motion capture system's marker

Number of cameras on the motion capture system is 8, and sampling rate is 100 Hz. Subjects are running 16 km/h at 6 different angles of inclination situation (angle of inclination: 0, 2, 4, 6, 8, 10).

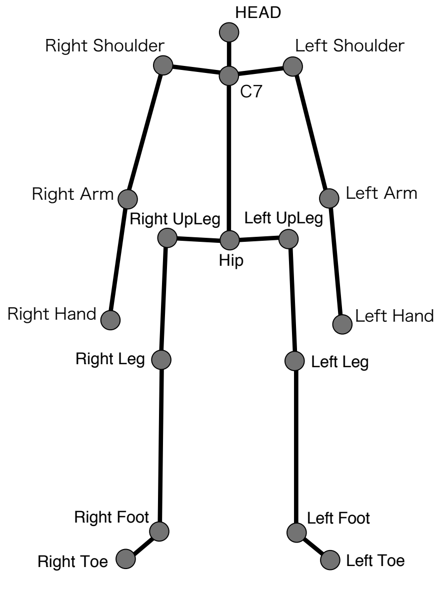

Figure 2: Human joint and its tag name

Table 1: Correspondence between tag name and joint name

Tag name	Joint name
HEAD	Top of head
C7	Lowest part of cervical spine
Right Shoulder	Right shoulder
Right Arm	Right elbow
Right Hand	Right hand
Left Shoulder	Left shoulder
Left Arm	Left elbow
Left Hand	Left hand
Hip	Waist joint
Right UpLeg	Right articulatio coxae
Right Leg	Right knee joint
Right Foot	Right pastern
Right Toe	Right Toe
Left UpLeg	Left articulatio coxae
Left Leg	Left knee joint
Left Foot	Left pastern
Left Toe	Left Toe

In this research, we analyze human motion using the 17 place (Figure 2) of the human joints 3-dimensional (x-y-z) time-series coordinates, estimated by the ViconMX^{TM} system. Correspondence between the tag name of Figure 2 and real human body's joint name is described in Table 2.

In the next session, we discuss the optimized movement based on the motion capture system's data.

3. Experiments and Results

We discuss the optimized movement based on the motion capture system's data. In this research, we focus on the human leg joint. We optimize the joint angle of grounding, and estimate the minimize impact value of grounding.

To be simplified the human leg, we consider the Figure 4 model. We assume equal spaced particle $(\mathbf{x}, \mathbf{y})$ under feet, and simulate the impact value of grounding. In this research, "impact value" means the impact acceleration of human waist joint. We compute the minimize impact acceleration of grounding under the constrained condition.

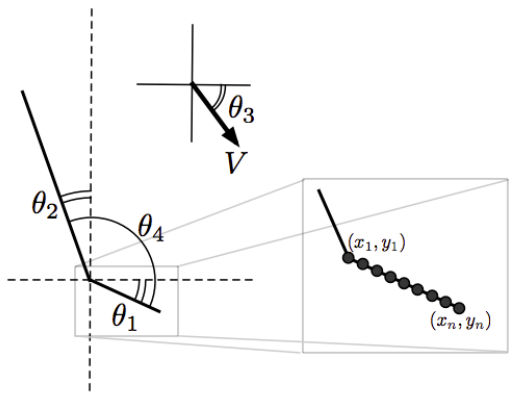

Figure 3: Human leg joint model

Here, θ_1 is ankle joint angle, θ_2 is crural interosseous angle, θ_3 is angle of fall, and θ_3 is angle between ankle joint and crural interosseous.

We define the infall velocity as V, moving velocity as U and particle i's impact acceleration at t as $A_{t,i}$. Total impact acceleration to the waist joint is

$$W_t = \sum_{i=1}^{n} A_{t,i} \sin\theta_3 \tan\theta_2 w_i. \quad (1)$$

Where w_i is the weight parameter of subject's grounding angle. If the subjects grounding from the heel, we assume that all impact acceleration is concentrate on the heel at the same time.

$$w_i = \begin{cases} (n, 0, \ldots, 0) & (\theta_1 > 0) \\ (1, 1, \ldots, 1) & (\text{Otherwise}). \end{cases} \quad (2)$$

From these assumptions, we estimate θ_1, θ_2 for minimize Eq.3 model's value. Note, parameter $\theta_1, \theta_2, \theta_4$ has onstrained condition based on the range of human gait movement.

$$\begin{aligned} & W_t = \sum_{i=1}^{n} A_{t,i} \sin\theta_3 \tan\theta_2 w_i \\ & \mathbf{w} = \begin{cases} (n, 0, \ldots, 0) & (\theta_1 > 0) \\ (1, 1, \ldots, 1) & (\text{Otherwise}) \end{cases} \\ & \max(W_t) \to \min \end{aligned} \quad (3)$$

We set the initial value of Eq.3 model, θ_1, θ_2 are subjects ankle joint angle and rural interosseous angle from the motion capture system. U, V, θ_3 are same as a observed value of the motion capture system. We estimate θ_1, θ_2 using SANN optimization method (R2.15.1), and iteration count as 10,000.

Experimental Result In this section, we show the single example of Section3 model. From the observed value, we set the initial value of θ_1, θ_2 as $\theta_1 = 18.6°, \theta_2 = 8.2°$, simulation result of optimized angle of θ_1, θ_2 are $\hat{\theta}_1 = -8.51°, \hat{\theta}_2 = 9.63°$.

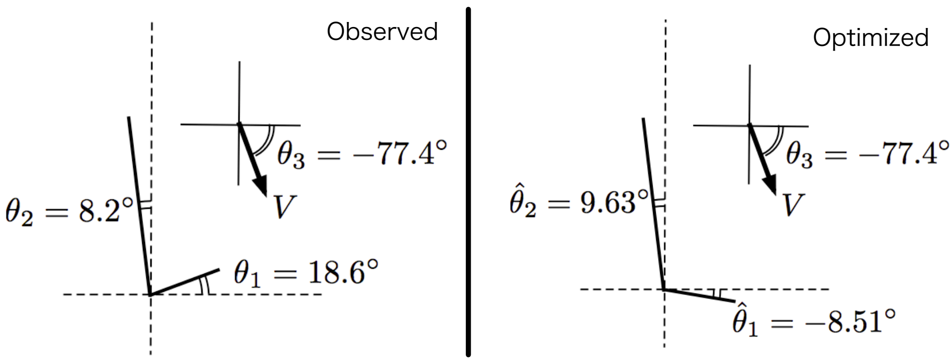

Figure 4: Observed and optimized value of joint angle

Max total impact acceleration value of observed value is 52.6m/sec^2, and optimized max total impact acceleration value is 39.6m/sec^2. From the optimization result of grounding angle, θ_1 is shift from elevation angle to depression angle. On the other hand,

θ_2 is almost same as the initial value. As a result, from the standpoint of the impact acceleration, grounding angle of the ankle joint is very important for the minimize the impact acceleration. If the ankle joint angle of grounding is depression angle, impact acceleration is able to minimize.

Figure5 is step vs. subjects total impact acceleration plot. Red and black solid lines are subjects observed acceleration and optimized subjects acceleration, respectively.

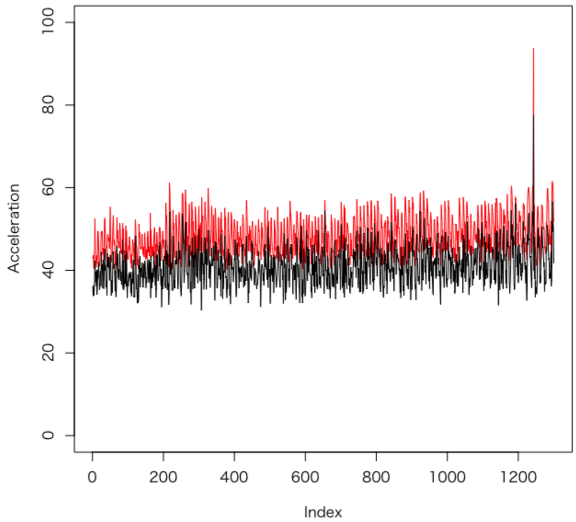

Figure 5: Observed and optimized value total impact acceleration value

From Figure5, ankle joint angle of grounding is very important role for the minimize the impact acceleration.

4. Conclusion

In this research, we propose the optimal movement estimation method based on the human joint model using motion capture system's 3-dimensional coordinate data. We focus on the human leg joint, optimize the joint angle of grounding, and estimate the minimize impact value of grounding. As a result, from the standpoint of the impact acceleration, ankle joint angle of grounding is very important for the minimize the impact acceleration.

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