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Skill Level Evaluation for Taijiquan Based on Curve Fitting and Logarithmic Distribution Diagram of Curvature

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Abstract: In this paper, we propose an objective skill level evaluation method for Taijiquan. The proposed skill level evaluation method utilizes both curve fitting to spiral motion and classification based on a logarithmic distribution diagram of curvature for a human body part. In order to demonstrate a possibility of the proposed method, we present experimental results with a Kinect sensor for three subjects, i.e., a beginner, intermediate and expert.

Key Words: skill level evaluation, Taijiquan, logarithmic distribution diagram of curvature, Kinect.

1. Introduction

This paper proposes a method to give an objective evaluation of the skill level in Taijiquan based on curve fitting and a logarithmic distribution diagram of curvature.

The number of elders who start learning Taijiquan to improve their health is increasing with the aging of society. In order to continue learning Taijiquan, it is necessary to evaluate objectively how much his skill level goes up. It is known that his passion for learning will be maintained when one can have a method to evaluate the skill level by oneself without depending upon the evaluation from an instructor [1],[2]. Furthermore, obtaining an objective index of the skill level is conductive to find motion to be corrected, and leads to an improvement of learning efficiency.

Learning Taijiquan on textbooks or DVD contents only shows shapes or time-varying movements of motion, but does not point out how a learner should correct his bad motion. Therefore, the instructor's evaluation can do nothing but be received in a Taijiquan classroom. However, the fact is that most of the evaluation is based on the subjective judgement [3],[4]. To the best of our knowledge, an objective evaluation based on a trajectory of the motion is hardly shown. Also, most previous works for Taijiquan have focused on the movement of the center of gravity of a human body, not on the trajectory of a human body part, e.g., see [5].

Here, a method that objectively evaluates an aesthetic curve based on a logarithm distribution diagram of curvature, developed in the field of the industrial design, has been proposed [6],[7]. In the field of the industrial design, objective evaluation of curves is performed by classifying them into five typical patterns. Accordingly, the proposed method is able to classify curves into the five patterns. Our idea lies in that a trajectory of body part motion in Taijiquan is regarded as an aesthetic curve and then objective evaluation of the skill level is obtained through the classification of the curve into the five patterns.

In this paper, we apply the evaluation method of an aesthetic curve to the evaluation of the skill level in learning Taijiquan. We regard the proposed method as an alternative to standard instructor judgement, but not professional jury one in an official game. The proposed method performs curve fitting to spiral motion in order to enhance the feature for an expert of Taijiquan before the classification using the logarithmic distribution diagram of curvature. In the experiment, the motion capture using a Kinect sensor makes it possible to obtain the trajectory of a human body part in Taijiquan with simple cost. It is found that the difference between an expert and a non-expert can be explained from the curve fitting and the classification through the experimental results.

2. Logarithmic Distribution Diagram of Curvature

A classification method through a logarithmic distribution diagram of curvature which shows characteristics of an aesthetic curve, i.e., curvature changes and a volume of a curve has been proposed in [6],[7]. The logarithmic distribution diagram of curvature is represented on a double logarithmic coordinates system whose horizontal and vertical axes represent an interval of a radius of a curvature $\bar{\rho}_i$ and a ratio of a length of a segmental curve to a total length of a curve $\bar{s}_i$, respectively. The interval $\bar{\rho}_i$ and the ratio $\bar{s}_i$ are calculated as follows:

$$\bar{\rho}_i = \frac{\rho_i}{S},\ \bar{s}_i = \log_{10}\left(\frac{s_i}{S}\right), \tag{1}$$

where ρ_i, s_i and S are a radius of a curvature at a constitutional point a_i, a length of a segmental curve and a total length of a curve, respectively.

In the field of the industrial design, it is reported that the logarithmic distribution diagram of curvature for an aesthetic curve can be classified into five typical types [6],[7]. The five typical types of the logarithmic distribution diagram of curvature are shown in Fig. 1. The effectiveness of the classification method based on a logarithmic distribution diagram of curvature has been verified through a few thousand real products including industrial products, shaped forms by nature and artifacts [8].

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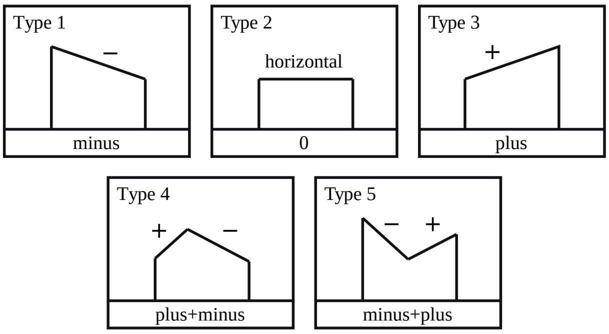


Fig. 1 Five typical types of logarithmic distribution diagram of curvature.

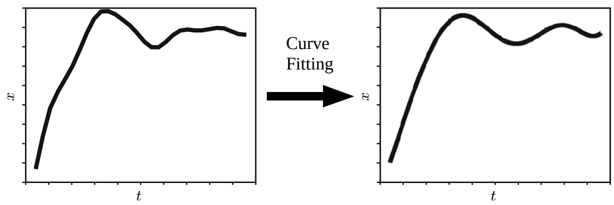


Fig. 2 Curve fitting using the spiral equations.

3. Skill Level Evaluation Method for Taijiquan

In previous works [6],[7], the classification method through the logarithmic distribution diagram of curvature is only applied to a shape of a product in the field of the industrial design. In this paper, we expand it to a skill level evaluation of human motion in Taijiquan.

3.1 Curve Fitting Using Spiral Equation

We interviewed an expert of Taijiquan to understand characteristics for motion of an expert in Taijiquan qualitatively. In the interview result, it is found that the motion of a Taijiquan expert has the feature of spiral motion. Then, it is indicated that the motion of an expert has a good curve fitting to an oscillation which is amplified or decayed.

In order to enhance the feature of an expert in Taijiquan, we perform curve fitting with the least-square method using a trigonometric function with the damping term which represents the feature of a spiral. The equations of the curve fitting for the position data $p = [x, y, z]^T$ are shown below.

$$x = f_x + e^{\frac{a_x t}{2}} \left\{ \sum_{i=1}^{n} \Big(b_{ix} \sin(c_{ix} t + d_{ix}) + e_{ix} \cos(c_{ix} t + d_{ix}) \Big) \right\}, \quad (2)$$

$$y = f_y + e^{\frac{a_y t}{2}} \left\{ \sum_{i=1}^{n} \Big(b_{iy} \sin(c_{iy} t + d_{iy}) + e_{iy} \cos(c_{iy} t + d_{iy}) \Big) \right\}, \quad (3)$$

$$z = f_z + e^{\frac{a_z t}{2}} \left\{ \sum_{i=1}^{n} \Big(b_{iz} \sin(c_{iz} t + d_{iz}) + e_{iz} \cos(c_{iz} t + d_{iz}) \Big) \right\}, \quad (4)$$

where f_k, a_k, b_{ik}, c_{ik}, d_{ik} and e_{ik} $(k = x, y, z)$ are unknown parameters. The spiral equations (2)–(4) are proposed based on the equation representing the damped oscillation. In order to fit multiple peaks of the trajectory, polynomials of trigonometric functions are utilized. Figure 2 shows a result of the curve fitting using the spiral equations for a curve.

3.2 Skill Level Evaluation Method Based on Curve Fitting and Logarithmic Distribution Diagram of Curvature

In this subsection, we propose the skill level evaluation method for Taijiquan based on the curve fitting and logarithmic distribution diagram of curvature. Our idea is that the trajectory of the expert's motion in Taijiquan is regarded as an aesthetic curve.

Table 1 Years of experience and frequency of training of Taijiquan.

	Years of Experience (years)	Frequency of Training (times per a week)
A (Beginner)	4	2
B (Intermediate)	8	2 or 3
C (Expert)	32	5–7

Firstly, we measure a trajectory of a human body part using a motion capture system, e.g., a Kinect system. It should be noted that our proposed evaluation method does not need the movement of the center of gravity of a human body which is more difficult to obtain accurately. Secondly, we utilize the smoothing differential method in order to remove noise of human motion and sensor noise from the measured position data. The equation of the smoothing differential method is shown as follows (See [9]):

$$\dot{p}(t_n) = \frac{1}{12} \big(-p(t_{n-3}) - p(t_{n-2}) - p(t_{n-1}) + p(t_{n+1}) + p(t_{n+2}) + p(t_{n+3}) \big), \quad (5)$$

where $p(t_n) = [x(t_n), y(t_n), z(t_n)]^T$ is the measured position data at time t_n.

Next, the curve fitting is performed using the spiral equations (2)–(4). It should be remarked that the motion of an expert has to be fit to the spiral well. In other word, the result of curve fitting by using the spiral equations (2)–(4) could catch the turning points in the motion. In particular, a key point for curve fitting in this research is that the shape of the fitting curve matches that of the measured data at the inflection points.

Finally, we draw the logarithmic distribution diagram of curvature in Section 2 using the radius of the curvature. If the result is classified as one of the five typical patterns in Fig. 1, it should be evaluated that the curve is aesthetic, i.e., the motion approaches an expert's motion. Considering the real instructor's judgement criteria, the skill level of a Taijiquan player could be high if his motion is similar to an expert's one. Therefore, the proposed method can evaluate the skill level through the classification between experts and others.

Figure 3 shows the flow diagram of the skill level evaluation for Taijiquan based on the curve fitting and logarithmic distribution diagram of curvature. It is important that the curve is fit to the spiral well and the logarithmic distribution diagram of curvature is classified into the five typical types. Our proposed objective evaluation of the skill level for Taijiquan will be obtained using both the curve fitting and the classification based on the logarithmic distribution diagram of curvature.

4. Experiment

In this section, we present experimental results in order to verify the effectiveness of the proposed method.

4.1 Experimental Setup

In this experiment, we compare motion of three human subjects, i.e., a beginner, an intermediate and an expert. Table 1 shows years of experience and frequency of training of Taijiquan for the three subjects. An experimental environment is shown in Fig. 4. The human motion capture system used in the experiment, consists of an off-the-shelf Microsoft Kinect [10]

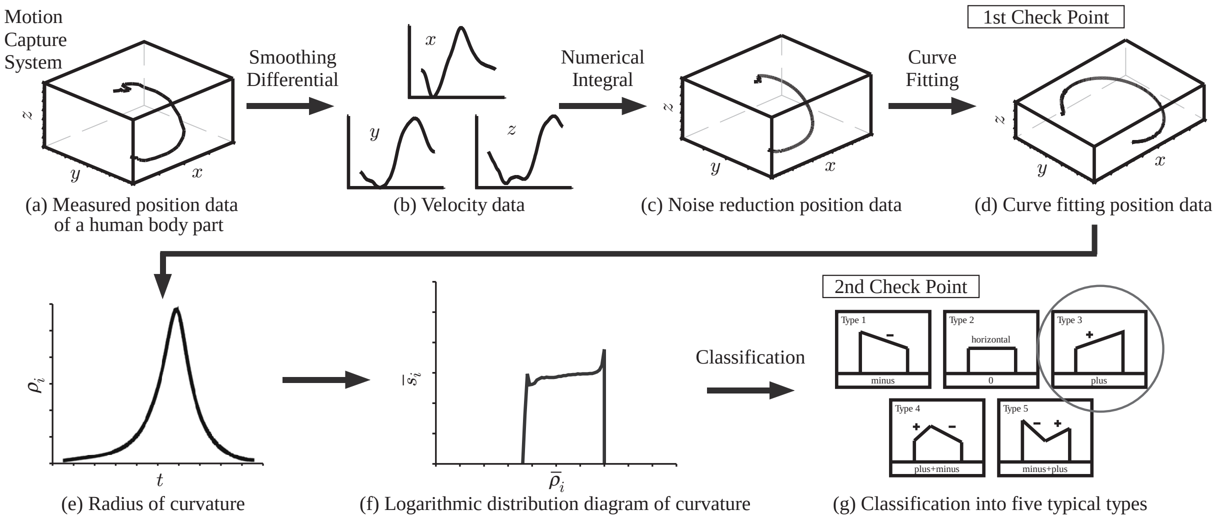


Fig. 3 Flow diagram of the skill level evaluation for Taijiquan based on the curve fitting and logarithmic distribution diagram of curvature.

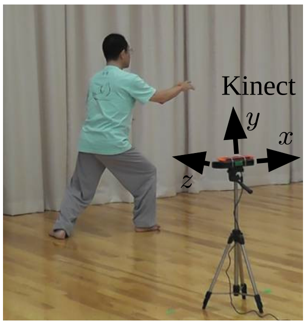


Fig. 4 Experimental environment.

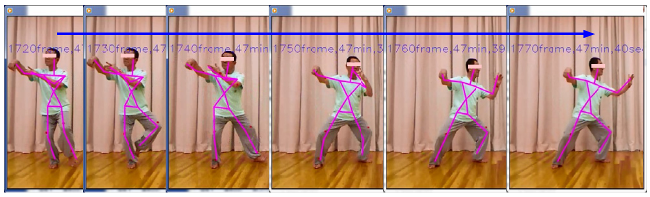


Fig. 5 Movement of a part of Yunshou.

and a laptop. The Microsoft Kinect, which utilizes the laptop, has a depth sensor, a RGB camera and a special microchip to track movement with a bone model. A player does not need any marker in order that the Kinect sensor system provides full body three dimensional motion capture. Hence, an advantage of the system is that both cost and a burden for the player are small. The Kinect sensor system creates a digital skeleton based on the bone model and depth data obtained from an infrared projector and a camera. The coordinate on the human body is automatically determined by the Kinect sensor system. Matching the digital skeleton to image data received from the RGB camera, the Kinect sensor system is capable of automatically calibrating the human motion based on their physical attribute.

After calibration, the Kinect sensor system can provide accuracy of depth reconstruction in the order of 1–4 cm at the range of 1–4 m [11],[12]. Typical errors for the pose estimation accuracy can be kept within about 5 cm [13]. The Kinect sensor motion capture algorithm works best when players are standing, the view is unobstructed and players body limbs are not interacting with objects [13]. In order to keep accuracy of the Kinect sensor motion capture, we set the Kinect sensor in the front of the Taijiquan players. Here, the position data can be derived automatically from the Kinect motion capture system, after a certain motion which an evaluator focused on is extracted manually from whole motion.

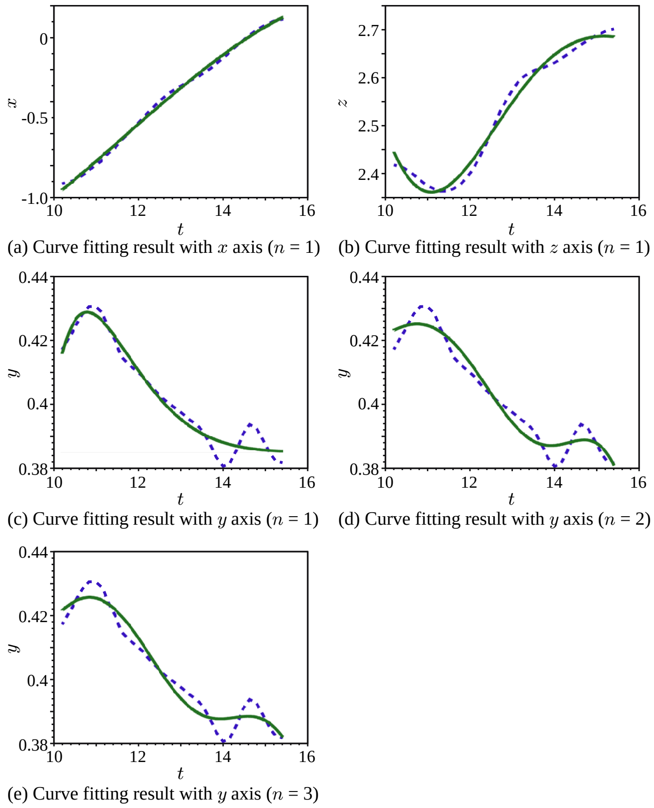
Three human subjects performed Yunshou, which is one of the 24 formulas of Taijiquan. Figure 5 shows movement of a part of Yunshou to which the proposed evaluation method is applied. In this experiment, we focused on the motions of their left wrists, since it was found through experimental analysis that features for movement of Yunshou prominently emerged in them.

The curve fitting was carried out by using the least-square method with Scilab. We set the initial values of the parameters f_k, a_k, b_{ik}, c_{ik}, d_{ik} and e_{ik} $(k = x, y, z)$ in Eqs. (2)–(4) to 1.

4.2 Experimental Results

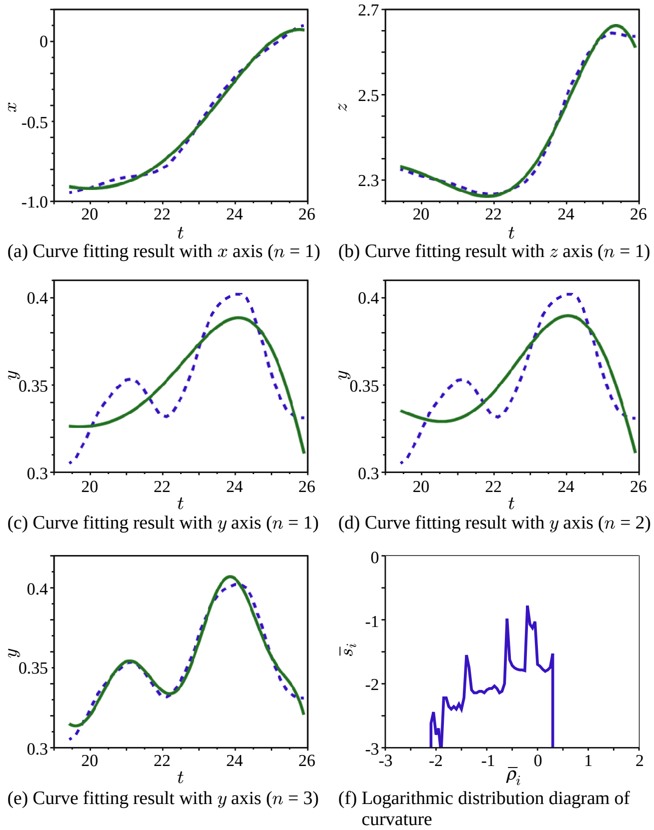
We present the experimental results for the skill level evaluation for Taijiquan in Figs. 6–8. Figures 6–8 show the results of the left wrist motion of the beginner, intermediate and expert, respectively. The dashed lines denote the measured position data with the smoothing differential method, and the solid lines denote the result of the curve fitting by using the spiral equations in Eqs. (2)–(4). The curve fitting results of the x axis and z axis are presented in Figs. 6–8 (a) and (b), respectively. Also, Figs. 6–8 (c), (d) and (e) show the curve fitting results of the y axis with $n = 1$, $n = 2$ and $n = 3$, respectively, in Eq. (3). Although the good curve fitting results of the x axis and z axis are obtained with $n = 1$ in Eqs. (2) and (4), that of the y axis could not catch the feature of the turning point. Figures 7 (f) and 8 (f) depict the logarithmic distribution diagram of curvature by using the curve fitting results of the x and z axis with $n = 1$ and that of the y axis with $n = 3$.

From Fig. 6, it can be verified that the curve fitting in the case of the beginner cannot pick up the feature of the turning point from the measured data at 14 s and 14.6 s obviously, in spite of increasing the number of the trigonometric function's component n. Whereas the good curve fitting can be obtained, Fig. 7 indicates that the logarithmic distribution diagram of cur-



(a) Curve fitting result with x axis (n = 1) (b) Curve fitting result with z axis (n = 1)
(c) Curve fitting result with y axis (n = 1) (d) Curve fitting result with y axis (n = 2)
(e) Curve fitting result with y axis (n = 3)

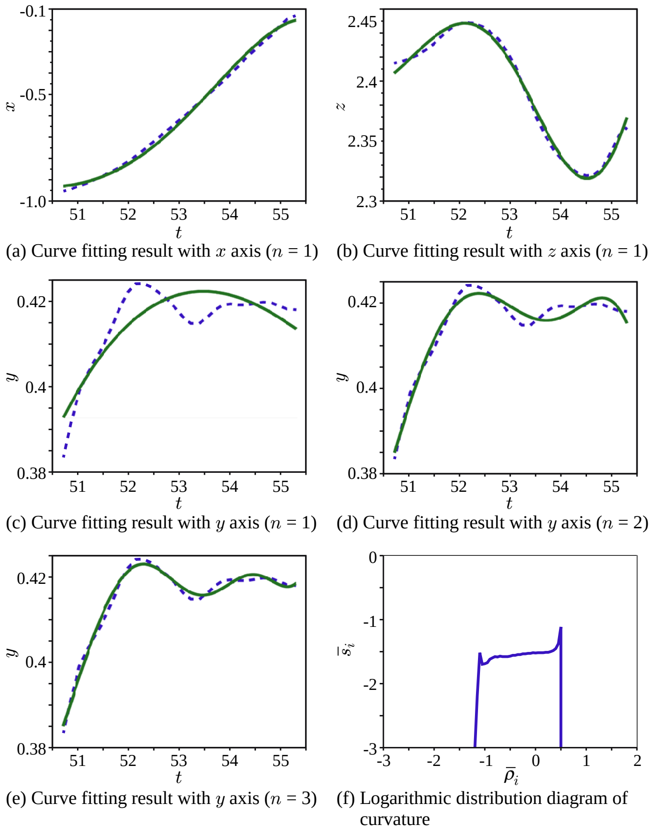
Fig. 6 Curve fitting of the beginner.



(a) Curve fitting result with x axis (n = 1) (b) Curve fitting result with z axis (n = 1)
(c) Curve fitting result with y axis (n = 1) (d) Curve fitting result with y axis (n = 2)
(e) Curve fitting result with y axis (n = 3) (f) Logarithmic distribution diagram of curvature

Fig. 7 Curve fitting and the logarithmic distribution diagram of curvature of the intermediate.

vature in the case of the intermediate cannot be classified into the five typical types in Fig. 1. On the other hand, in the case of the expert, it is found that the curve fitting can capture the turning point of the measured data, and the logarithmic curva-



(a) Curve fitting result with x axis (n = 1) (b) Curve fitting result with z axis (n = 1)
(c) Curve fitting result with y axis (n = 1) (d) Curve fitting result with y axis (n = 2)
(e) Curve fitting result with y axis (n = 3) (f) Logarithmic distribution diagram of curvature

Fig. 8 Curve fitting and the logarithmic distribution diagram of curvature of the expert.

ture histogram is classified as the plus type which is one of the five typical types. This implies that the motion trajectory of the expert which needs the feature of the spiral can be regarded as an aesthetic curve in the field of the industrial design. From these experimental results, it can be confirmed that the objective evaluation of the skill level for Taijiquan can be presented by using both the curve fitting and the classification based on the logarithmic distribution diagram of curvature.

5. Conclusions

In this paper, we present the objective skill level evaluation method for Taijiquan. This method utilizes both the curve fitting to the spiral motion and the classification based on the logarithmic distribution diagram of curvature for a human body part. The advantage of the proposed method does not need to measure the movement of the center of gravity of a human body. Although the number of subjects are small, we present experimental results of the beginner, intermediate and expert with the Kinect in order to demonstrate a possibility of the proposed method.

In the field of Taijiquan, standard evaluations to skill level are usually given by each expert instructor. It is fact that an evaluation method has not been formalized yet so that anybody can measure skill level easily. In this background, we have to start the verification of the proposed evaluation method based on one evaluation of only one reliable instructor. As the result, we could provide equivalent experimental results to a real-world skill level evaluation one, i.e., an instructor visual judgement one. However, we know that the more we increase the number of subjects, the more objective our proposed evaluation become. Possible future work involves an increase in the number of subjects and Taijiquan formulas for experimental verification and numerical evaluation for skill level of Taijiquan. We will also improve the acquisition procedure of position data to be able to extract a judged motion from whole motion automatically.

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