A Study of an Automated Scoring System for the Twist Skill in Horizontal Bar of Artistic Gymnastics

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ABSTRACT

This paper presents an automated scoring system for the twist skill in Horizontal bar based on motion image analysis. In this system, training scenes of Horizontal bar are taken by a high-speed video camera, and then a gymnast's region is extracted from a video image frame by frame based on a background subtraction method. Next, the body axis of the gymnast in the moment when a twist skill completed is estimated from the gymnast's region. Finally, the deduction point for the twist skill is automatically decided according to the rules described in the Code of Points. In experiments using video images for 26 practices, it was shown that about 80.8% of the correspondence rate between estimated deduction scores and true ones calculated by the correct 'SCF' and 'Body axis' was obtained. This can be promising as a result at the preliminary stage of this research.

Keywords: An Event Scored by Judges, Image Processing, High-Speed Video Camera

1. INTRODUCTION

Artistic gymnastics is one of physical exercises where a gymnast performs short routines on apparatus including Horizontal bar, Floor and Vault, and is one of sports where judges evaluate difficulty of skills and physical strength in each event. However, the opportunity that gymnasts are evaluated by judges is limited at some official competitions. Therefore, an automated scoring system which can be used in usual training has been strongly desired.

We are developing an automated scoring system from a video sequence, and now are focusing at Horizontal bar (or High bar) event. There are few researches regarding automated scoring system from video sequence as one of human behaviour analysis. As previous works, Hoshino et.al [1] proposed an automated recognition system for basic element skills, such as jump and spin, from video sequences of figure skating taken by several cameras. However, they have not achieved to give score to each skill. Also, Shin et.al [2] proposed a scoring method for revolution skills in Horizontal bar event. In the research, each skill obtained from a video sequence is compared in the skill database and identified its skill's name and the skill's point. Furthermore, the deduction point of each skill is evaluated by comparing with the skillful gymnast's performance. However, their method is no more than relative evaluation. For practical use, an absolute evaluation system is indispensable.

In this paper, we propose a quantitative evaluation method for twist skills which account for from 40% to 70% of all skills in a routine of Horizontal bar event. First of all, we introduce the scoring system of Artistic gymnastics, and then, propose our method for extracting gymnast's region from a video sequence and estimating a deduction point. Finally, experimental results and their considerations are described.

2. CODE OF POINTS

In Artistic Gymnastics, the final score of a routine is decided as the sum total of D score and E score. D score indicates 'Difficulty score' and is given by difficulty of each skill and its combinations included in a routine. E score indicates 'Execution score' and is given the degree of perfection of each skill by deduction system. Even if D score is high, the advantage will be lost when E score becomes low. That is, gymnasts usually have to be aware of their possibility of the deduction. The basic score and point deduction rule for each skill are defined in the Code of Points [3] and judges decide total score of a routine according to the Code of Points. Therefore, an automated scoring system according to the Code of Points is needed.

In this study, we focus on a twist skill in Horizontal bar event. Because twist skills are included from 40% to 70% of all skills in a routine, we considered the influence that these skills gives to the final score will be very important. As one of the point deduction on twist skills of Horizontal bar event, the angle between the vertical axis and the body axis at the moment of completion of a twist motion (when the gymnast grips the bar again after once his hand was released from the bar) is evaluated as shown in Fig.1. For example, if the angle becomes 40 degrees, the twist skill is deducted by 0.1 point.

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3. EVALUATION PROCEDURE FOR TWIST SKILLS

In this chapter, we concretely describe a procedure for evaluating twist skills of Horizontal bar event from a video sequence. Fig.2 shows an example of a video sequence including a twist skill. We extract a gymnast's region from input data as shown in Fig.2, and then, the body axis and the moment of skill completion are estimated. Finally, the deduction point for the twist skill is decided according to the rules as shown in Fig.1. The details of each process composed in our procedure are shown below.

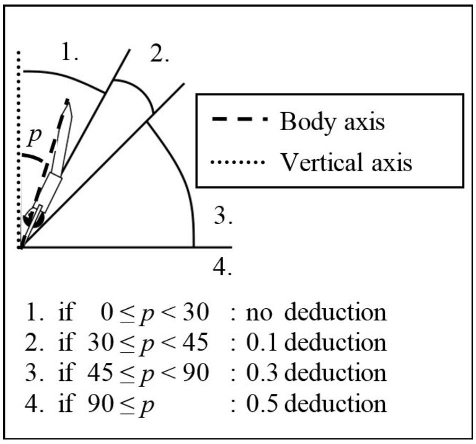

Fig.1: *Deduction rule for a twist skill defined by the Code of Points.*

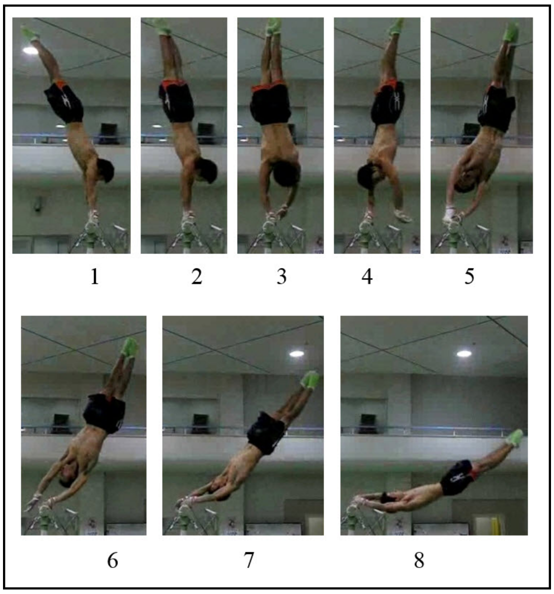

Fig.2: *Example of a video sequence including twist skills.*

3.1 Extraction of Gymnast's Region

In this study, a high-speed video camera is used to capture gymnast's quick motions, and the camera is set up so that the optical axis of the camera corresponds to the axis of the steel bar. Because a high-speed video camera is used inside a gymnasium, many flickers will be appeared in the video image, under the influence of the lighting environment. Therefore, a statistical background subtraction method with the normal distribution is employed to extract the gymnast's region from noisy images. First of all, a background model is generated. Fig.3 shows an example of a background image. N background images are taken in advance. Let $f(x_{n,i})$ be the pixel value at the pixel x_i of the n-th background image, and μ_i and σ_i be the mean value and the standard deviation at the pixel x_i for the given background images, respectively. The mean value and the standard deviation can be calculated as follows.

$$\mu_i = \frac{1}{N}\Sigma_{n=1}^{N} f(x_{n,i}) \quad (1)$$

$$\sigma_i = \sqrt{\frac{1}{N}\Sigma_{n=1}^{N} f(x_{n,i})^2 - \mu_i^2} \quad (2)$$

Let $f(x_i)$ be the pixel value at the pixel x_i.The candidate pixel of gymnast's region can be calculated by

$$f(x_i) = \begin{cases} 1; & \|x_i - \mu_i\| \geq k\sigma_i \\ 0; & otherwise \end{cases} \quad (3)$$

where k means a adjustable parameter, and if $f(x_i) = 1$ then it is regarded as the candidate pixel. After that, the region with maximum area size is decided as a gymnast's region.

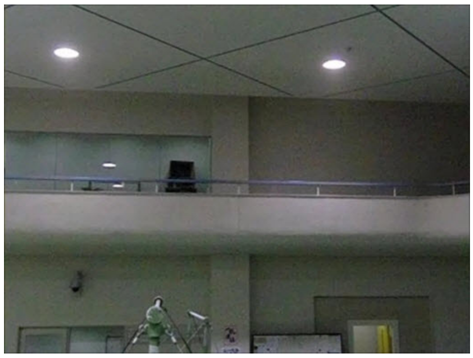

Fig.3: *Example of a background image.*

3.2 Estimation of Twist Skill Completion

A method for estimating the moment when a twist motion completed is described. When a gymnast is doing twist motion, the apparent area size of the gymnast's breast width becomes wider on the two dimensional image. This feature is easily observed from Fig.2. Therefore, the number of pixels on the gymnast's region lying between a circle with the radius of R_i and a circle with the radius of R_o is used as a feature for recognizing the twist motion. The feature at a certain video frame t is calculated by

$$g_t = \Sigma_j(f(x_j) \mid R_i \leq \; \|x_j - C\| \; \leq \; R_o) \tag{4}$$

where C indicates the revolution center on the image, and R_i is always shorter than R_o. This feature is also illustrated in Fig.4. In this figure, a white color region indicates the extracted gymnast's region. Practically, the variables R_i and R_o are decided so as to include the gymnast's breast region.

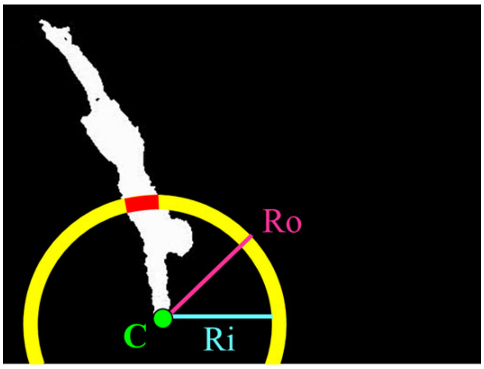

Fig.4: *The breast region for twist recognition.*

To identify the video frame when a twist skill completed, the time variation of the feature g_t is used. While normal giant swing is executed, g_t is expected to become almost constant. However, when a giant swing with a twist is executed after a normal giant swing, a remarkable change similar to a sine wave is appeared twice sequentially in the graph of the time variation as shown in Fig.5. In the graph of raw data, many noises are included, so noise reduction process by median filtering is executed. Accordingly, the video frame is decided to be the moment when the value of g_t returns into a usual range after the pair of a local maximum and a local minimum were appeared twice. If the value of g_t doesn't return into the usual range, the video frame is decided to be the moment the pair of a local maximum and a local minimum are appeared twice.T_1 means the lowest value of the usual range of the feature g_t. The local maximum and local minimum are obtained by the following conditions,

$$\begin{cases} localmax : g_t - g_{t-1} > T_h \text{ and } g_t - g_{t+n} > T_h \\ localmin : g_{t-n} - g_t > T_h \text{ and } g_{t+n} - g_t > T_h \end{cases} \tag{5}$$

where n is a positive integer and indicates the interval of the frame number, T_h is the thresholding value, and these values are given by experimentally.

3.3 Estimation of Deduction Point

A body axis which becomes basis for estimating a deduction point is extracted as a line segment connecting between a hand and a tiptoe on the image at the twist completion frame. A quadrilateral circumscribing on the gymnast's region is calculated and then four points which touch the quadrilateral are selected. By comparing distances between each two points, the two points with the longest line are selected. To reduce the influence of noise such as flicker, the gravity center points of the gymnast's region around each selected point are regarded as the points which become endpoints of the body axis. The points obtained from this process mentioned above are shown in Fig.6 and Fig.7, respectively.

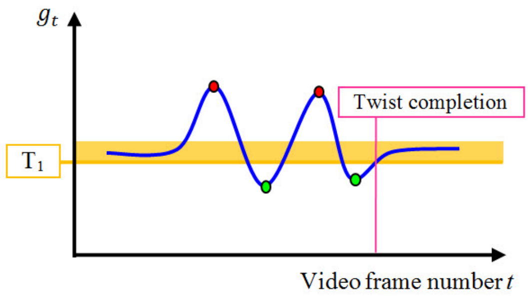

Fig.5: *Time variation of the breast area.*

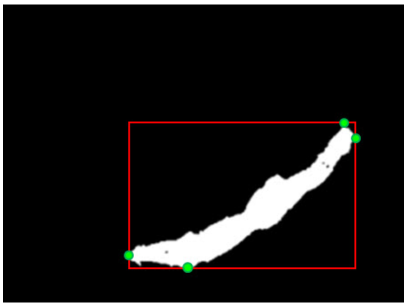

Fig.6: *The four points touching a quadrilateral.*

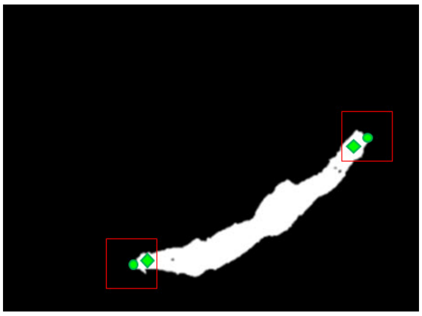

Fig.7: *The estimated hand point and tiptoe point.*

As the result, the angle between the body axis and a vertical axis is calculated, and the deduction point for a twist motion is obtained according to the rule described in Fig.1.

4. EXPERIMENTS

In experiments, we focusing on the twist skill called "Giant swing fwd. with 1/1 turn in double el-grip". This skill was performed by three university gymnasts having 10 to 12 years' experience, and a total of 26 practices were taken by a high-speed video camera (CASIO EX-FH20) with the sampling rate 210 fps and image size 480x360 pixels in our university gymnasium. The camera placement is shown in Fig.8. The camera is fixed on condition that it's optical axis become parallel to the revolution axis of Horizontal bar. The parameters used here are N = 100, k = 2.0, R_o = 115, R_i = 125, T_h = 3 and n = 20.

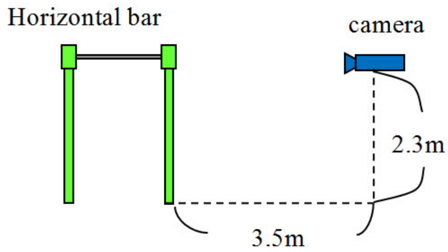

Fig.8: *Camera placement.*

Fig.9 shows an example of the input video sequence including a twist motion and the result of gymnast's region extraction. About the extraction results, some root-like noises were appeared but we think there is no influence for succeeding processes. Also, a line segment in the figure indicates the estimated gymnast's body axis at the moment twist motion was completed.

From the extracted gymnast's regions like the binary images in Fig.9, the time variation of the area size of the breast region was obtained. The result with noise reduction by median filter is shown in Fig.10.

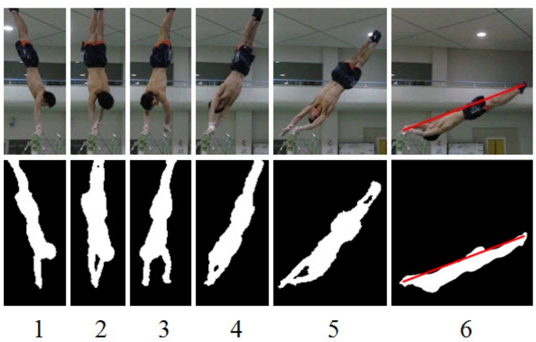

Fig.9: *Examples of video sequence and the extracted gymnast's region with the estimated body axis.*

The results of accuracy evaluation for all 26 practices are shown in Table 1. 'SCF' means the estimated video frame number at the moment a twist motion was completed, 'result' indicates that the video frame number calculated by the proposed method, and 'err' indicates the difference from the correct video frame number given manually. 'Body axis' means the estimated angle of a gymnast's body axis, 'Deduction' means the deduction point for the twist

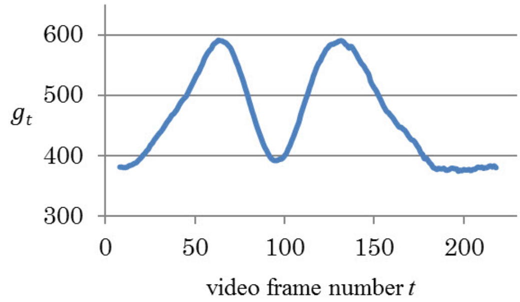

Fig.10: *The time variation of the feature of a breast region.*

skill, and each 'err' indicate the difference from the correct value. Average errors about 'SCF', 'Body axis' and 'Deduction' became 13.0 frames, 0.68 degrees and 0.02 points, respectively. The correspon-

Table 1: *Evaluation results of twist skill.*

	SCF		Body axis		Deduction	
data #	result	err	result	err	result	err
1	216	6	57.35	0.65	0.3	0.0
2	221	11	73.32	-0.05	0.3	0.0
3	194	-16	63.44	0.88	0.3	0.0
4	211	1	66.00	0.16	0.3	0.0
5	196	-14	64.92	-2.45	0.3	0.0
6	212	2	67.32	0.79	0.3	0.0
7	224	14	73.42	-0.33	0.5	-0.2
8	236	26	65.31	0.74	0.5	-0.2
9	230	20	65.34	0.49	0.3	0.0
10	212	2	83.36	1.09	0.3	0.0
11	204	-6	58.21	-0.08	0.3	0.0
12	221	11	68.20	0.04	0.3	0.0
13	198	-12	64.16	0.05	0.3	0.0
14	191	-19	66.52	0.09	0.3	0.0
15	236	26	70.74	2.16	0.5	-0.2
16	216	6	74.58	0.42	0.3	0.0
17	193	-17	68.62	0.49	0.3	0.0
18	231	21	69.46	0.28	0.5	-0.2
19	229	19	55.80	0.85	0.3	0.0
20	217	7	72.09	0.26	0.3	0.0
21	186	-24	69.02	0.22	0.3	0.0
22	224	14	63.35	-0.36	0.3	0.0
23	193	-17	64.23	0.26	0.3	0.0
24	216	6	73.57	0.71	0.3	0.0
25	212	2	72.53	-0.21	0.3	0.0
26	229	19	74.03	0.93	0.5	-0.2

dence rate between the estimated deduction score and the true score calculated by the correct 'SCF' and 'Body axis' given manually was about 80.8%, and we think that it was satisfying results as a preliminary stage of this research. About SCF, the average error 13.0 is equivalent to about 0.06 seconds. Because an average gymnast revolves about 13 degrees in 0.06 seconds, this average error is higher than we think. However, the result of estimating gymnast's body axis was good, so we think that the accuracy for deduction score becomes higher by improving the estimation method of 'SCF'.

The effectiveness of this system was shown by comparing between the estimated deduction score by the proposed method and those by judges. The results for all 26 practices by nine judges are shown in Table 2. All the judges have the certificate of Japan. There are three types of certification. 'Category 1' is the highest level in Japan and it is possible to judge all the Japan's competitions. 'Category 2' can judge the district competitions, and 'Category 3' can judge the prefectural ones. The letter 'A' to 'I' show the judge's ID who cooperated with our experiment. The comparison between the estimated deduction score by the proposed method and those by judges is shown in Table 3. 'Deduction' means the deduction score by the proposed method. 'All' shows the deduction score obtained by majority decision by nine judges in Table 2. In the same way, 'Cat.1', 'Cat.2' and 'Cat.3' shows the deduction score obtained by three judges who are belonging to each category. For the deduction score by 'All', 'Cat.1', 'Cat.2' and 'Cat.3', each correspondence rate with the score by the proposed method was 80.8%, 76.9%, 80.8%, and 80.8%. These results show the possibility that the proposed system can be used as an assist tool in usual training.

5. CONCLUSION

In this paper, we proposed a method for quantifying the deduction point for a twist skill from video sequences of Horizontal bar event in Artistic gymnastics. In experiments, we focused on the twist skill called "Giant swing fwd. with 1/1 turn in double el-grip", and a total of 26 practices were evaluated by the proposed method. As the results, gymnast's regions and their body axis could be also stably extracted. The correspondence rate between the estimated deduction score and the true score calculated by the correct 'SCF' and 'Body axis' given manually was about 80%, and we think that it was satisfying results as a preliminary stage of this research. Moreover, the correspondence rate between the estimated deduction score and those by the actual judges was about 80%. From this result, we think that the proposed system can be useful in daily training.

As future works, we try to improve estimation accuracy of the twist completion frame, to consider other deduction items and to apply it to other events such as Floor Exercise, Vault and so on.

6. ACKNOWLEDGMENT

The authors thank members of Artistic Gymnastics Club in Chukyo University for cooperation in ex-

Table 2: *Evaluation results of twist skill.*

	Category 1			Category 2			Category 3		
data #	A	B	C	D	E	F	G	H	I
1	.3	.3	.3	.3	.3	.3	.3	.3	.3
2	.3	.3	.3	.3	.3	.3	.3	.3	.3
3	.3	.3	.3	.3	.3	.3	.3	.3	.3
4	.1	.1	.3	.3	.3	.1	.3	.3	.3
5	.3	.3	.3	.3	.3	.3	.3	.3	.3
6	.3	.3	.3	.3	.3	.3	.3	.3	.3
7	.3	.3	.3	.3	.3	.3	.3	.3	.3
8	.1	.3	.3	.3	.3	.3	.3	.3	.3
9	.3	.3	.3	.3	.3	.3	.3	.3	.3
10	.3	.5	.3	.3	.3	.3	.3	.3	.3
11	.3	.1	.3	.3	.3	.3	.3	.3	.3
12	.3	.3	.3	.3	.3	.3	.3	.5	.3
13	.3	.3	.3	.3	.3	.3	.3	.3	.3
14	.3	.1	.3	.3	.3	.3	.3	.3	.3
15	.3	.3	.3	.3	.3	.3	.3	.3	.3
16	.3	.3	.3	.3	.3	.3	.3	.3	.3
17	.3	.3	.3	.1	.3	.3	.3	.3	.3
18	.3	.3	.3	.3	.3	.3	.3	.3	.3
19	.3	.3	.3	.1	.3	.3	.3	.3	.3
20	.3	.3	.5	.3	.3	.3	.3	.3	.3
21	.3	.3	.3	.1	.3	.3	.3	.3	.3
22	.3	.3	.3	.3	.3	.3	.3	.3	.3
23	.1	.3	.3	.3	.3	.3	.3	.3	.3
24	.3	.3	.3	.3	.3	.5	.3	.5	.3
25	.1	.3	.3	.3	.3	.3	.3	.3	.3
26	.3	.3	.3	.3	.3	.3	.3	.3	.3

Table 3: *Comparison between the estimated deduction score by the proposed method and those by judges.*

data #	Deduction	All	Cat.1	Cat.2	Cat.3
1	0.3	0.3	0.3	0.3	0.3
2	0.3	0.3	0.3	0.3	0.3
3	0.3	0.3	0.3	0.3	0.3
4	0.3	0.3	0.1	0.3	0.3
5	0.3	0.3	0.3	0.3	0.3
6	0.3	0.3	0.3	0.3	0.3
7	0.5	0.3	0.3	0.3	0.3
8	0.5	0.3	0.3	0.3	0.3
9	0.3	0.3	0.3	0.3	0.3
10	0.3	0.3	0.3	0.3	0.3
11	0.3	0.3	0.3	0.3	0.3
12	0.3	0.3	0.3	0.3	0.3
13	0.3	0.3	0.3	0.3	0.3
14	0.3	0.3	0.3	0.3	0.3
15	0.5	0.3	0.3	0.3	0.3
16	0.3	0.3	0.3	0.3	0.3
17	0.3	0.3	0.3	0.3	0.3
18	0.5	0.3	0.3	0.3	0.3
19	0.3	0.3	0.3	0.3	0.3
20	0.3	0.3	0.3	0.3	0.3
21	0.3	0.3	0.3	0.3	0.3
22	0.3	0.3	0.3	0.3	0.3
23	0.3	0.3	0.3	0.3	0.3
24	0.3	0.3	0.3	0.3	0.3
25	0.3	0.3	0.3	0.3	0.3
26	0.5	0.3	0.3	0.3	0.3

periments, and colleagues of Hasegawa and Taki laboratory for discussion.

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