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SMASH MOTION ANALYSIS FOR BADMINTON FROM IMAGE

Makiko NAGASAWA† *Yoshinori HATORI*† *Mitsugu KAKUTA*‡ *Tadao HAYASHI*‡ *Yoshio SEKINE*‡

†Interdisciplinary Graduate School of Science and Engineering, Tokyo Institute of Technology
‡Faculty of Sport Science, Nippon Sports Science University

ABSTRACT

In sports competition asked for high performance, analysis including a detailed motion is important. This study proposes a method for analyzing a human motion from badminton smash image. The proposed method maps a human motion in the Space-G, which expresses position-time with the KL transform, to the Space-V, which expresses position-velocity. The method classifies the motion of the target part into the three shapes, a circle, a curve, and a line (or a point). Theoretic verification of the proposed method by computer simulation was performed and an experiment using the Japanese elite players' data was conducted. The results are discussed in the three viewpoints, the principle of the calculation, application to multiple players and sports science.

1. INTRODUCTION

Image processing [3] is applied to various fields of sports, such as motion analysis, game analysis [31,38], and physical education. In sports analysis, a human motion is one of the crucial points. The elucidation of the human motion is advanced by the research in biomechanics etc [17]. In recent years, the following two things were clarified in biomechanics research. First, some typical parts of the body have contributed to general movement of human. Next, the information on these typical parts roughly expresses general movement of human. On the other hand, in sports competition asked for high performance, analysis including a detailed motion is important [21]. With the camera for such analysis, image is obtained by non-contact to the object to be measured. Moreover, there is little unnecessary load to a player at the time of processing or analysis. Therefore, image processing is an effective means in a sports field [42].

The player's performance improvement is performed in the field of sports competition by judgment by a supervisor and a coach with years of experience [18]. When making such a judgment, the numerical value presented by the science staff, who is a member of the team for the player strengthened, is the information that can perform intelligible distinction. However, a numerical value has a subject as a means by which an understanding can be obtained by the staff. Here, an important thing is development of the means intuitively conveyed to a player, a supervisor, and a coach. Image is used in information feedback about the motion that has strong influence against a player's performance. The image system that can evaluate the position of each part of the body etc. is widely applied not only in badminton but in the whole sports field [32,43,44,46,52,56]. A wire frame animation is one of the most typical things of such an imaging system. Especially the system that can perform 2 screen displays simultaneously is useful [19]. Such a system is an effective means by which information is given intuitively to the player, the supervisor, and the coach who distinguish the difference in operation.

Smash in a badminton game is an important shot used as an offensive starting point [12,20,33]. This shot may turn into a shot that determines a victory of a game [2]. At this time, speed change of a shuttle serves as a range from about 400km/h of initial velocity [59] to 0km/h [54]. Thus, in order to analyze movement characterized by comparatively big change for a short time, some subjects occur. In this subject, it is one of the solutions to use a high frame rate camera. However, generally frame rate and resolution (or SN) of an imaging system are a trade-off. For this reason, the image of a shot or a body part is obtained under comparatively bright environment. Thus, since the performance of a visual system is covered, the environment (for example, lighting) of the circumference of it may be improved. Even in this case, the cause and effect of a motion can be found from an image. However, a motion of a subject may not become clear to the problem in a game. In such a problem, it is difficult to clarify the essence of the problem only by the environmental improvement for image, or the improvement in imaging system performance. Moreover, the speed of a badminton game has risen in the last several years. This factor is in the improvement in tools performances, such as sports science research and a racket, rule amendment, etc [1,5,31,60]. The consideration to such an external factor is also important in order to perform improvement in performance by suitable judgment. Now, the information including data from the science staff is needed by the player, the supervisor, and the coach as an important thing [32].

From the above background, development of the system according to the purpose is performed on the occasion of the image analysis for Badminton competition [47,48]. For such a development, both the hardware (camera system) [47] that has a standard that can be used widely, and software (algorithm) suitable for a game and/or play need to be realized [31]. This paper proposes a novel method for analyzing a motion from badminton smash image. The proposed method pays its attention to a smooth motion of the body in a smash. Moreover, this method calculates analysis based on mapping the information on the space (Space-G) of position-time to the space (Space-V) of position-velocity. In general object movement, the locus is a circle, a curve or a line (or a point) in Space-V. This classification is applied to the analysis of a human motion (a repetitive motion, the motion to one way, a stop) in this research. Image obtained by proposed method enables visual distinction of the difference in a motion of a player. For this reason, application can be considered as an index that shows the form at the time of good condition. First, this paper describes the proposed method. Next, the verification result by the computer simulation based on this method is shown. Moreover, the experiment using the Japanese elite player's data is conducted, and the possibility of proposed method is considered. Furthermore, applications of the image analysis to Badminton competition are also discussed from a viewpoint of sports science.

2. PROPOSED METHOD

In this method, using image, firstly the camera coordinate system of data extracted from video need to be transformed to a coordinate system centered at the center part of human body (body coordinate system). This process is to create a space where characteristics of movement of the body standardized by the Karhunen-Loeve (KL) transform [22] are specified. Then, mapping to Space-V will be done. Generally, this can also be applied to data obtained from various physical sensors. In this research, differences of the size of movement caused by differences in build, conditions of setting the cameras and the difference of players' dominant hand can be considered in processing image using the method based on video. This will be described in section 5.1.

2.1. Coordinate system centered at the center part of the body

Transformation of an image $\boldsymbol{f}(t)\big(= (x(t), y(t), z(t))\big)$ in the camera coordinate system to the body coordinate system is expressed as

$$\boldsymbol{g}_{s,p}(t) = \boldsymbol{f}_{s,p}(t) - \boldsymbol{f}_{s,rp}(t) \qquad (1)$$

where t denotes time, s denote player and p denotes a part of the body respectively. Note that S is the number of the players, P is the total of the parts of the body to be analyzed and T is the finish time of the motion. Also, rp denotes the reference point of the body in the analysis and we have

$$\boldsymbol{f}_{rp}(t) = \boldsymbol{g}_o(t) \qquad (2)$$

where o denotes the center of the body coordinate system.

Next, Space-G, which is temporal change of a body part $\boldsymbol{g}_{s,p}$, is defined as

$$\boldsymbol{g'}_{s,p}(t) = \boldsymbol{g}_{s,p}(t) * \mathbf{U} \qquad (3)$$

where $\mathbf{U}$ is orthogonal basis of G. The position of $\boldsymbol{g}_{s,p}$ is transformed into $\boldsymbol{g'}_{s,p}$ by (3) and the space defined by $\mathbf{U}$ reflects the characteristics of movement as temporal change**.** The reason that $\mathbf{U}$ is a matrix with 3 rows and 3 columns is because $\mathbf{U}=[\boldsymbol{u_1}, \boldsymbol{u_2}, \boldsymbol{u_3}]$, which specifies the characteristics of the motion of one part, is defined with respect to the space defined by the orthogonal basis of the body coordinate system. These $\boldsymbol{u}_i$ have relations $\mathbf{R}\boldsymbol{u}_i = \lambda_i \boldsymbol{u}_i$ and this is an eigenvalue problem [22]. In this research, an eigenvector $\boldsymbol{u}_i$ corresponds to the ith ($1 \leq i \leq 3$) eigenvalue λ_i ($\lambda_1 \geq \lambda_2 \geq \lambda_3$) of an autocorrelation matrix $\mathbf{R}$ of $\boldsymbol{g''}_{\boldsymbol{p}}$ obtained by standardizing the data $\boldsymbol{g_p}$ with $T \cdot S$ rows and 3 columns that describes temporal changes of a certain part p of S players.

Table.1 Motion classification of human in sports

Velocity \ Form	Smooth		Not smooth	
Smooth	Repetition	Fig.3	Repetition	—
	Motion in one direction	Fig.5	Motion in one direction	—
	Constant velocity motion	Fig.7	Constant velocity motion	—
Not smooth	Repetition	Fig.4	Repetition	—
	Motion in one direction	Fig.6	Motion in one direction	—
	Constant velocity motion	Fig.8	Constant velocity motion	—

2.2. Space-V for Analysis

Mapping from Space-G to Space-V after the preceding section 2.1. is defined as

$$V^{[T_1,T_2]} = M \circ G^{[T_1,T_2]}. \qquad (4)$$

This calculation is generally differential calculus. However, in the proposed method, the calculation is done by differences between the positions of the digital images before and front a certain time t ($T_1 \leq t \leq T_2$) based on the frame rate of the video. Let Space-G denote the whole space composed of position and time, and Space-V denote the whole space composed of position and velocity, mapping M defines the differences between the components of space $G^{[T_1,T_2]}$ in Space-G and space $V^{[T_1,T_2]}$ in Space-V. We propose this Space-V as the space for analysis in this research.

3. COMPUTER SIMULATION

Classification of human motion in the computer simulation for validation against the proposed method is shown in Table.1, where movement like coming back to the same position as the arm rotated (repetition) is i) and motion in one direction like follow through that should be followed with the shot (the swing of the arm when throwing the ball etc [52,56].) is ii). Then, motion performed by human can be expressed by combination of i) and ii). Besides, constant velocity motion (iii)) including a stop point during the motion is considered. Note that a motion with a constant velocity that is not smooth in form in Table.1 is a stop, that is, its velocity equals to zero. In addition, simulation about motion of which form is not smooth is omitted this time because movement of each parts of the body is smooth in principle during the so-called good movement. Regarding the simulant of these three motions, i) repetition, ii) motion in one direction, and iii) constant velocity motion, which are often seen in sports exercises, the classification from the point of view of smoothness of the direction of the forth (the form) and the way of applying the forth (the velocity change) is shown in Table.1. It is expected that the results of the simulation are classified into three different forms on account of the principle of the proposed method described in the preceding section.

First, repetition move is shown in Fig.1 and Fig.2. In these figures, (a), (b) and (c) represent the motion in

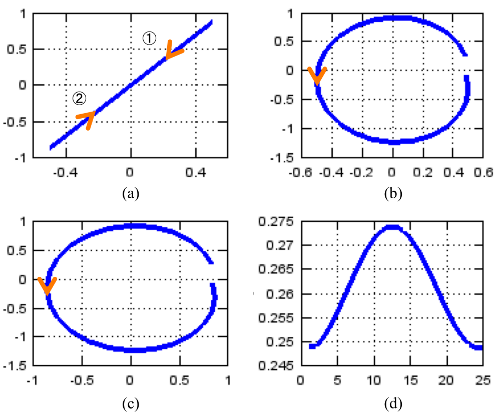

Fig.1 Repetition 1 [(a) Vertical axis:Y, Horizontal axis:X, (b) Vertical axis:Z, Horizontal axis:X, (c) Vertical axis:Z, Horizontal axis:Y, (d) Vertical axis:velocity, Horizontal axis:time]

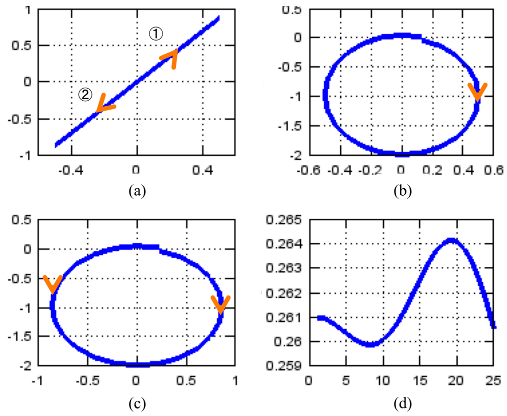

Fig.2 Repetition 2 [a] Vertical axis:Y, Horizontal axis:X, (b) Vertical axis:Z, Horizontal axis:X, (c) Vertical axis:Z, Horizontal axis:Y, (d) Vertical axis:velocity, Horizontal axis:time]

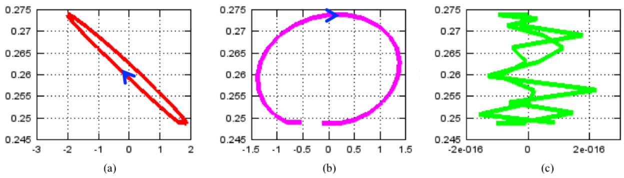

Fig.3 Results from computer simulation (I-1) [Vertical axis:verocity, Horizontal axis of (a), (b) and (c) are first principle component, second principle component, third principle component, respectively]

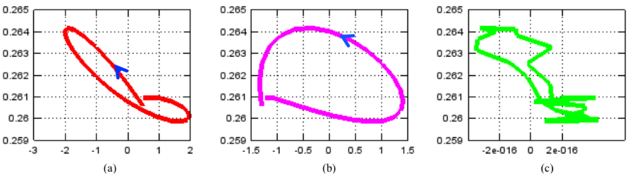

Fig.4 Results from computer simulation (I-2) [Verticalaxis:verocity, Horizontal axis of (a), (b) and (c) are first principle component, second principle component, third principle component, respectively]

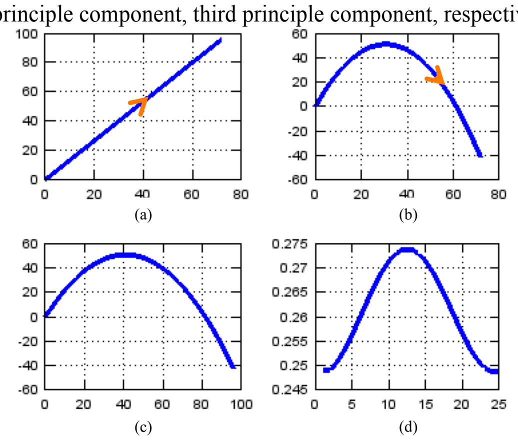

Fig.5 Motion in one direction 1 [(a) Vertical axis:Y, Horizontal axis:X, (b) Vertical axis:Z, Horizontal axis:X, (c) Vertical axis:Z, Horizontal axis:Y, (d) Vertical axis:velocity, Horizontal axis:time]

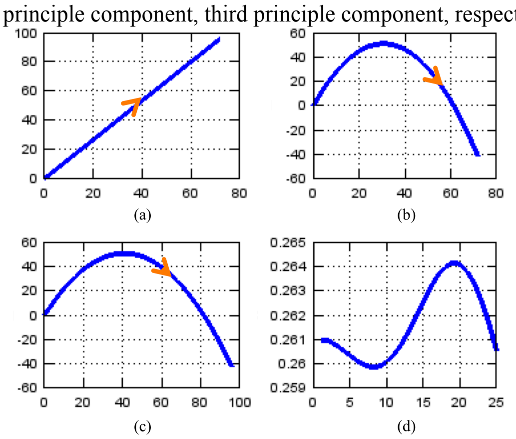

Fig.6 Motion in one direction 2 [a] Vertical axis:Y, Horizontal axis:X, (b) Vertical axis:Z, Horizontal axis:X, (c) Vertical axis:Z, Horizontal axis:Y, (d) Vertical axis:velocity, Horizontal axis:time]

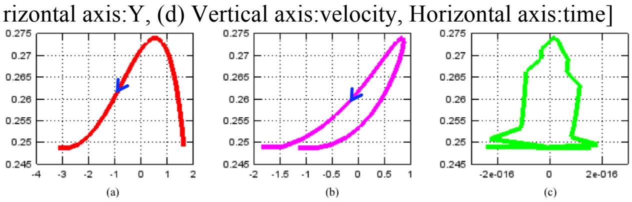

Fig.7 Results from computer simulation (II-1) [Vertical axis:verocity, Horizontal axis of (a), (b) and (c) are first principle component, second principle component, third principle component, respectively]

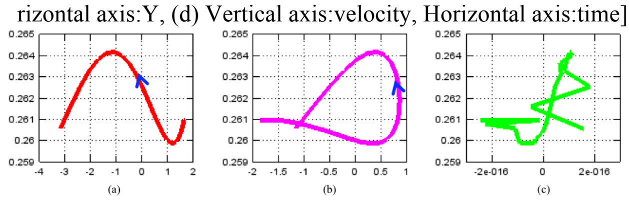

Fig.8 Results from computer simulation (II -2) [Verticalaxis:verocity, Horizontal axis of (a), (b) and (c) are first principle component, second principle component, third principle component, respectively]

Space-G and are projections of the data on XY plane, XZ plane and YZ plane respectively. Besides, the velocity change of the motion is shown in (d) simply as the speed. The arrows in the figures (→) represent the direction of the motion trajectory. If there are two or more arrows on one trajectory, it means that the trajectory overlap and the numbers of the arrows in the figures indicate the order of them. Comparing with Fig.1 and Fig.2, the form of the motion is similar and the latter part of the speed change is also similar although the entire of the changes in the speed is different. Thus, they are judged as same motion in wireframe video. To solve this problem, for example, it is considered that standardized processing in the temporal axis like setting the moment at impact as the basis. However, it is difficult in general because of the difference in build and individuality of each player. Therefore, wireframe video or the speed of the shuttle is compared in the present circumstances. The results of the analysis of these motions in Space-V are shown in Fig.3 and Fig.4. In these figures, (a), (b) and (c) represent the result in Space-

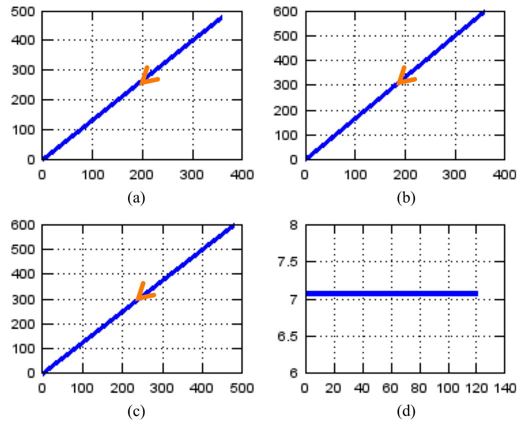

Fig.9 Constant velocity motion 1 [(a) Vertical axis:Y, Horizontal axis:X, (b) Vertical axis:Z, Horizontal axis:X, (c) Vertical axis:Z, Horizontal axis:Y, (d) Vertical axis:velocity, Horizontal axis:time]

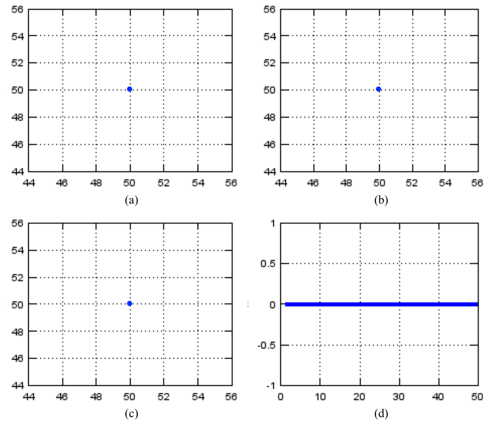

Fig.10 Constant velocity motion 2 [(a) Vertical axis:Y, Horizontal axis:X, (b) Vertical axis:Z, Horizontal axis:X, (c) Vertical axis:Z, Horizontal axis:Y, (d) Vertical axis:velocity, Horizontal axis:time]

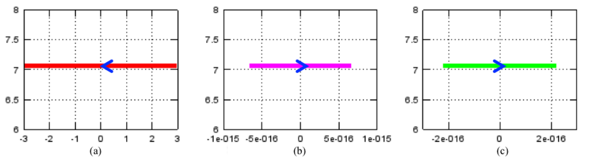

Fig.11 Results from computer simulation (III -1) [Vertical axis:verocity, Horizontal axis of (a), (b) and (c) are first principle component, se cond principle component, third principle component, respectively]

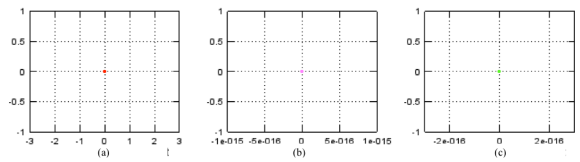

Fig.12 Results from computer simulation (III -2) [Verticalaxis:verocity, Horizontal axis of (a), (b) and (c) are first principle component, se cond principle component, third principle component, respectively]

V and are projections of the result on planes with the speed and the first orthogonal basis (KL1-v), the second orthogonal basis(KL2-v), and the third orthogonal basis (KL3-v) respectively. Here, the result on the KL3-v plane is approximately linear. As a result, it was found that the form of repetition in Space-V is a circle. The differences of these motions are shown in the results even in the case that these are judged as same motion in wireframe video as described above. Next, motion in one direction like follow through is shown in Fig.5 and Fig.6. These motions have the same form and the different velocity change, and they are recognized as same motion in wireframe video. The results of the analysis of these motions in Space-V are shown in Fig.7 and Fig.8. Both are curve lines in Space-V, however they are obviously different. Thirdly, constant velocity motion is shown in Fig.9 and Fig.10. Note that the latter is a stop point (that is, the constant velocity is zero). The results of the analysis of these motions in Space-V are shown in Fig.11 and Fig.12. They are linear in Fig.11. Note that Fig.12 shows a point because stop point is not moving although its result is indeterminate from calculation. The range of Fig.12 is the same as that of Fig.11. Therefore, as these results, a circle corresponds to repetition, a curve line corresponds to motion in one direction, and a straight line (or a point) corresponds to a constant velocity motion in Space- V.

4. EXPERIMENT

The computer simulation in the previous section indicates that the results in accordance with the principle of the proposed method can be obtained with the data having no errors. It is suggested that human motion can be classified using the proposed method by the results of the simulation. Based on it, in this section, an experiment with real data will be shown.

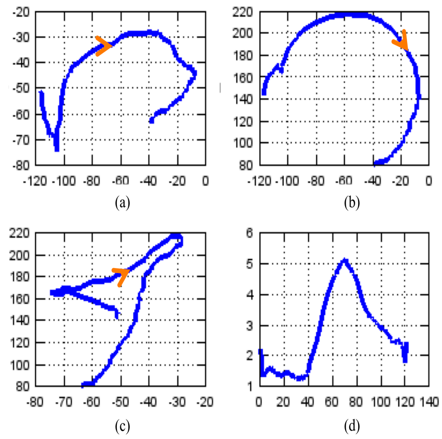

Fig.13 Motion of racket grip during smash [(a) Vertical axis:Y, Horizontal axis:X, (b) Vertical axis:Z, Horizontal axis:X, (c) Vertical axis:Z Horizontal axis:Y, (d) Vertical axis:velocity, Horizontal axis:time]

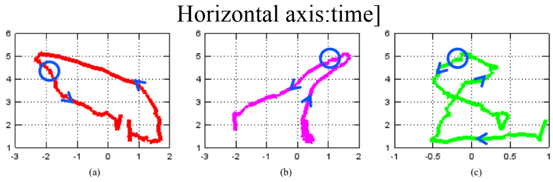

Fig.14 Experimental results [Vertical axis:velocity, Horizontal axis of (a), (b) and (c) are first principle component, second principle component, third principle component, respectively]

The proposed method was applied to the data of Japanese elite players [55]. The object of the experiment is the racket grip part during smash motion. Although this part is not a part of human body technically, it is fruitful for sports analysis because the part is moved as a result of the movements of some parts including the hand, which has a relatively high degree of freedom [1,35,40]. The flow of experiment consists of recording the smash motion, extraction of the information from the video, analysis, and displaying the result in series. The lower chest is treated as the center of the human body in this experiment [9,28]. Coordinates of the data from the video recorded from three directions by an HD camera are obtained by digitizing the video with characteristics of badminton [26,27,29,45,53]. This three dimensional information is calculated by the DLT method [25]. The proposed method was applied to the data processed as described above.

A form of an actual motion performed by a player is shown in Fig.13. In this figure, (a), (b) and (c) are projections of original data on XY plane, XZ plane and YZ plane in Space-G respectively. Besides, the velocity change of the motion is shown in (d) simply as the speed. The result in Space-V of the motion is shown in Fig.14. In this figure, the projections of the result on KL1- v plane, KL2- v plane and KL3- v plane in Space-V are represented. Contribution ratios of each orthogonal basis obtained by the KL transform are 50%, 40%, and 10% respectively. In Fig.14, ○ shows the point of impact (at the moment when the racket hits the shuttle). From a relation about impact of the racket head and the shuttle, it is indicated that the point of impact is after the point that racket grip has the highest speed during smash motion and it agrees with the knowledge of sports science.

5. DISCUSSION

5.1. Analysis in Simple Space-V

Here, the principle of the proposed method is discussed. Movement of an object in Space-G expressed in position and time can be mapped to the space expressed in position and velocity. The space after this mapping is the simple Space-V. On the other hand, in this research, the data in Space-G after the KL transform is mapped into Space-V. Such a mapping enables application to a player's condition, a stroke, shot prediction, and a player's comparison, etc. The results of example movements in both this simple Space-V and the Space-V of our research are shown in Fig.15,16,17, respectively. Two example movements which have the same speed change, similar form, different size of the form, and different position are shown in Fig.15 as the movements A and B. Fig.16 and Fig.17 are the results in the simple Space-V and the proposed Space-V, respectively. This comparison between these figures shows that the proposed method has an invariant feature to the difference in the size of a motion and the player's dominant hand. From the above thing, Space-V of the proposed method performs a classification called a circle of a closed loop, a curve, and a line (or a point) to a player as well as to a motion with individual difference, respectively.

5.2. Analysis for Multiple Players

Here, discussion about an experiment is performed. Generally, on the problem dealt with in this research, the KL transform can be adapted to an overall motion of the body or a partial motion (of each body part). The purpose of former application is to analyze time variation of all the body parts (all the p) of one player. The result in this case

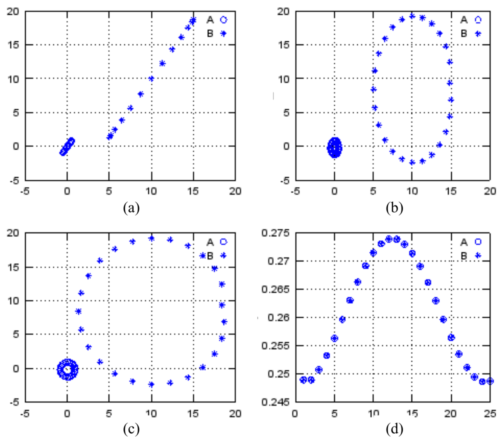

Fig.15 Experimental result in Space-G [(a) Vertical axis:Y, Horizontal axis:X, (b) Vertical axis:Z, Horizontal axis:X, (c) Vertical axis:Z Horizontal axis:Y, (d) Vertical axis:velocity, Horizontal axis:time]

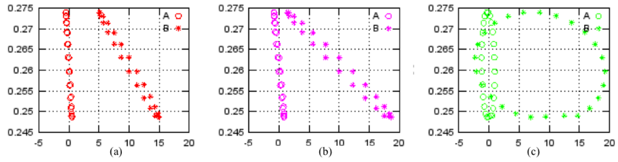

Fig.16 Experimental result in simple Space-V [Vertical axis: velocity, Horizontal axis of (a), (b) and (c) are X, Y and Z, respectively]

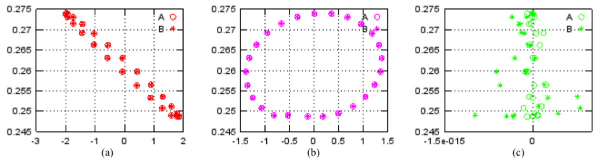

Fig17 Experimental result in Space-V [Vertical axis:velocity, Horizontal axis of (a), (b) and (c) are first principle component, second principle component, third principle component, respectively]

is a numerical value showing the combination and the contribution of the body parts which express the feature of a smash motion. This KL transform is conversion to the feature space showing a human motion, and computes the principal components that compose linear combination of each part of the body expressing a series of motions. On the other hand, the latter application is analyzing variation of a specific part of the body to multiple players. An actual experiment to multiple players is shown in Fig.18. The result in this analysis space is in Fig.19. The results of the motions by elite players' high level is obtained. In Fig.19, in comparison at the plane of the first principal component and the speed, this result shows that all the players' locus tended to have been alike. From the result, it is indicated that the motion which has the higher contribution to smash is alike among players. As for this, the result about general movement is the same as that of [37]. On the other hand, in comparison at the plane of the 3rd principle component and the speed, a different tendency among players is shown in Fig.19. The result shows that there are certain differences in the motions that are thought as with relatively little variation [7,11,15,34,41,51,58]. Although this may be one of the expected results, such a research on a motion is very interesting from a viewpoint of sports science. It is because that what has been overlooked by the conventional visual system may become clear. For example, a player's individuality may become clear. Thus, differences that

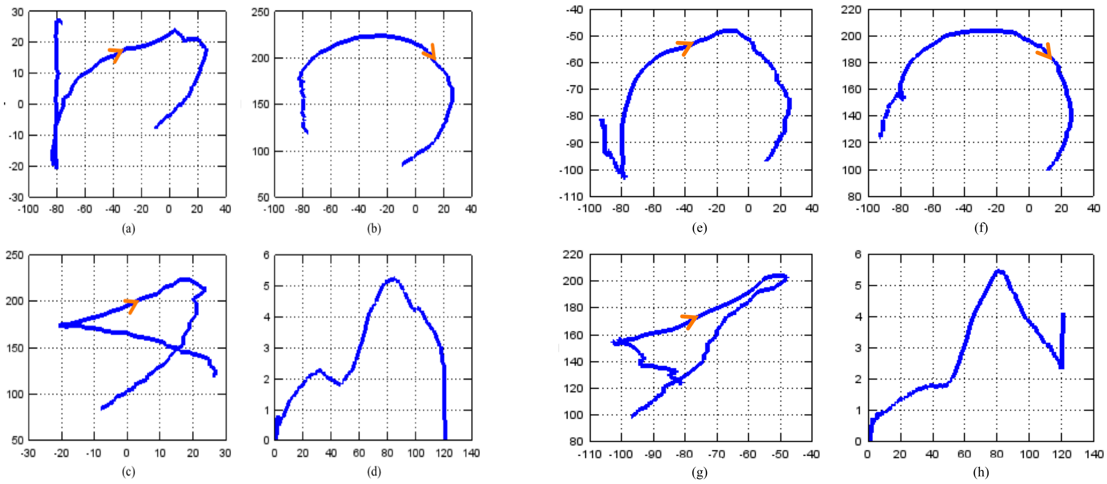

Fig.18 Motion of multiple players [(a)/(e) Vertical axis:Y, Horizontal axis:X, (b)/(f) Vertical axis:Z, Horizontal axis:X, (c)/(g) Verticalaxis:Z Horizontal axis:Y, (d)/(h) Vertical axis:velocity, Horizontal axis:time]

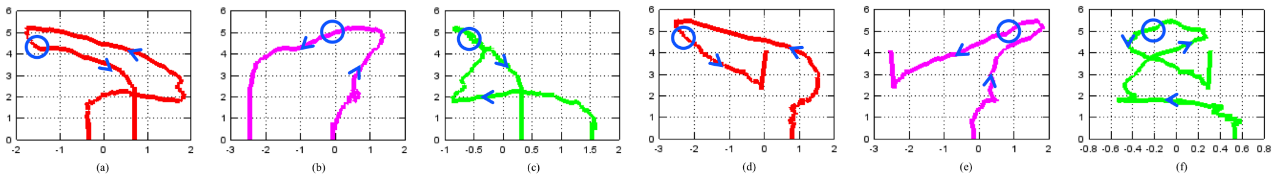

Fig.19 Experimental results of multiple players [Vertical axis:velocity, Horizontal axis of (a)/(d), (b)/(e) and (c)/(f) are first principle component, second principle component, third principle component, respectively]]

were not understood only by seeing an image directly or glancing at a wire frame animation can be displayed on our Space-V. This result has suggested that the proposed method can distinguish the difference in a delicate motion. This is because the proposed method classifies a motion into three basic patterns. With the three patterns, a closed loop, a curve, and a line (or a point), this research aims at the classification of a human motion, and has various directions in future use. By fusion in the knowledge of sports science, the proposed method may serve as an effective means for discovery of a new motion. In addition, the thing that the starting point and the terminal point of a motion in an experiment are not connected differs from the theory. This causes the start of the motion and the last position in not being coincided completely in the human motion. Although this is a future subject, a solution by normalization of the data for making the starting point and the terminal point into a closed loop could be considered.

5.3. Applications for Sports Science

Here, discussion from a viewpoint of sports science is performed. The proposed method in this paper is applicable to the multiple parts of the body about one player. Such an application tells the form which shows the motion for every part of a smash motion, and its speed. This analysis may show a series of time shift as a motion of each part [14,24,49,50]. This result serves as important information for improvement in performance, such as a player's physical condition, a player's comparison, and construction of tactics. Moreover, various kinds of physical sensors can be used to calculate the absolute value of the power generated in a motion [23]. Calculation by the proposed method can also be performed to the numerical value acquired from such physical sensors. About the sensors to attach, the sensitivity adjustment is required. This adjustment is performed for an accurate display about a series of human motions that are hard to be distinguished by glimpse from a wire frame display. However, such an adjustment is generally performed from viewpoints of SN of an image etc. at the time of image acquisition of sports, and it is not special. Furthermore, extended application of the proposed method has a player's positioning check in the scene of the drill practice used as a repetition of movement from the image of the player taken from a distance [10,13,39]. In badminton, a player has basic practice of returning to a ready position [16,57], after hitting a shot [4,6,30].

6. CONCLUSION

The novel method for badminton smash motion analysis was proposed. This method maps the human motion in the Space-G, which expresses position-time with the KL transform, to the Space-V, which expresses position-velocity. This KL transform is performed about the target body part in Space-G, and analysis of a human motion is conducted in Space-V.

Theoretic verification based on the proposed method by computer simulation was performed in this paper. Next, the result of an experiment using data of Japanese elite player was shown, and the possibility about the proposed method was shown. Furthermore, discussion about the proposed method was performed from the three viewpoints of the principle of the calculation, application to multiple players, and sports science. The proposed analyzing method classifies the target part into the three shape(s) (a closed loop, a curve, a line) as a relative motion to the center of the body, respectively. This classification roughly divides a human motion and discovery of a new motion is urged to it to a player, a supervisor, and a coach. There is no such a feature in the conventional wire frame animation. Moreover, there will be an application as a new index of a human motion. For example, it is thought that the proposed method is applicable to the new discovery of a human motion brought about by development of future sports science and the analysis of a humanoid robot which mounted the motion good at human. A future subject has normalization of the data for performing error analysis and 3D display for showing the results etc. In addition, actual physical quantity, such as momentum and torque, is calculable with combined use of various physical sensors [8] at the time of photography of a human motion. About the information from such a sensor, the proposed method can perform calculation with this information.

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