# Skeleton-Based Action Analysis for Improving Jump Height in Volleyball

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**Abstract**

This study aims to improve the jumping height for spiking in volleyball through skeleton-based action analysis using the Azure Kinect DK. Building on previous studies, this work focuses on the stride length, arm swing height, and spine angle during the jumping motion. Experiments are conducted to compare the effects of relatively better and relatively worse executions of these movements on jumping height. The results indicate that a relatively better stride length resulted in a significant increase of 187 mm in jumping height, while a relatively better arm swing height led to a 34 mm increase. However, variations in spine angle do not produce a significant difference in jumping height. These results suggest that optimizing stride length and arm swing height can effectively enhance the jumping performance of volleyball players.

**Keywords**

Skeleton-based action analysis, Volleyball, Azure Kinect DK

## 1. Introduction

Volleyball is a globally popular sport, with 800 million players who play volleyball at least once a week [1]. In Japan, volleyball enjoys widespread popularity and is extensively taught in physical education classes at both secondary and high schools. The implementation rate of volleyball in these schools is impressively high, reaching 99% in secondary schools and 97% in high schools [2]. Among the seven basic volleyball skills listed in the Fédération International Volleyball Federation (FIVB) Coaching Manual (Level 1), spiking stands out as a critical component, often determining the outcome of matches [3]. Effective spiking relies heavily on the player's ability to jump high, making the improvement of jumping techniques essential for competitive success.

Despite the importance of spiking, coaching methods often rely on qualitative instructions such as "swing your arms higher" or "jump with an awareness of pulling your body up." These instructions, while helpful, can sometimes lead to misunderstandings between coaches and players, particularly when the coaches lack experience in the sport. According to a study by the Japan Sports Agency, there is a significant shortage of qualified coaches at various levels, with 78.6% of respondents indicating a shortage at the JSPO Coach 2 level, which is responsible

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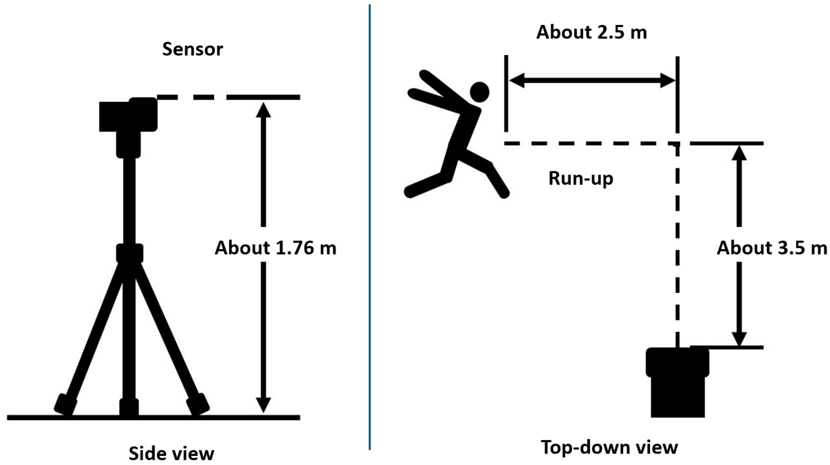


**Figure 1:** installation conditions of the Kinect sensor

for club activities [4]. This shortage underscores the need for more effective and accessible coaching methods.

In recent years, extensive research has been conducted on AI-based motion analysis in sports, showcasing the potential of AI coaching [5, 6, 7]. Technologies such as motion capture and skeleton-based analysis provide detailed and quantitative insights into athletic performance, offering a potential solution to the challenges faced in traditional coaching [8].

This study aims to improve the jumping height for spiking in volleyball through skeleton-based action analysis using the Azure Kinect DK. By focusing on key factors such as stride length, arm swing height, and spine angle, this research seeks to determine how variations in these movements affect jumping height. Through this analysis, the study aims to provide coaches and players with more precise and actionable feedback, ultimately enhancing the effectiveness of volleyball training and performance. The rest of this paper is organized as follows: Section 2 introduces the method and algorithm in this study. Section 3 shows the experimental results. Section 4 gives a brief discussion and finally section 5 concludes this paper.

## 2. Methods

Figure 1 shows the installation conditions of the sensor during the experiment. The sensor was placed on a tripod at a height of about 1.76 m. The starting position for the jump was about 3.5 m to 4 m from the sensor and about 2.5 m to the left of the sensor. The reason for starting the running aids from the left side is to make it easier to detect the subject's right arm from the direction of the sensor since the subject raises his right arm during jumping as part of the experimental procedure. If the subject runs from the opposite side, his right arm will be hidden by his upper body, and the sensor may not be able to detect it properly. This measurement records the three-dimensional joint coordinates of 32 points during the movement shown in Figure 2 [9].

From the joint coordinates obtained, the stride length, hand height, and spine angle are

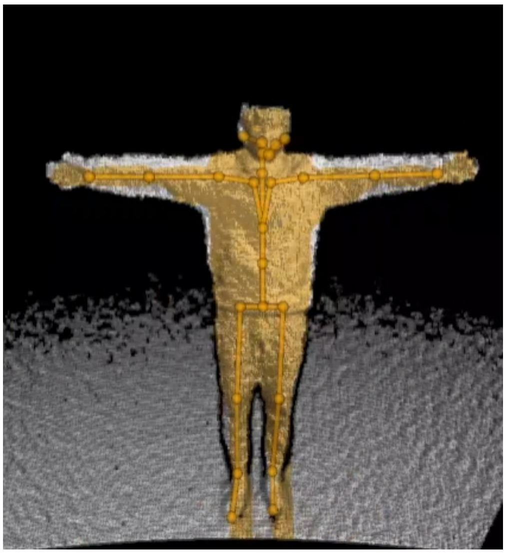

**Figure 2:** measurement records the three-dimensional joint coordinates [9]

analyzed. The derivation of stride length was calculated as follows.

$$D = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2 + (z_1 - z_2)^2} \tag{1}$$

The hand height during the backswing is derived from the equation of the plane of the floor and the distance between the joint points. The equation of the plane is obtained by the following equation.

$$ax + by + cz + d = 0 \tag{2}$$

The coefficients $a$, $b$, $c$, and $d$ in this equation are expressed by the following equations (3)–(6) when there exist four 3-dimensional coordinates $(x_1, y_1, z_1)$, $(x_2, y_2, z_2)$, $(x_3, y_3, z_3)$, $(x_4, y_4, z_4)$.

$$a = y_2(z_3 - z_4) + y_3(z_4 - z_2) + y_4(z_2 - z_3) \tag{3}$$

$$b = z_2(x_3 - x_4) + z_3(x_4 - x_2) + z_4(x_2 - x_3) \tag{4}$$

$$c = x_2(y_3 - y_4) + x_3(y_4 - y_2) + x_4(y_2 - y_3) \tag{5}$$

$$d = -x_2(y_3z_4 - y_4z_3) - x_3(y_4z_2 - y_2z_4) - x_4(y_2z_3 - y_3z_2) \tag{6}$$

The distance D between a point and a plane is obtained from the equation of the plane shown in equation (2) and the 3-dimensional coordinates $(x_1, y_1, z_1)$ as follows.

$$D = \frac{|ax1 + by1 + cz1 + d|}{\sqrt{a^2 + b^2 + c^2}} \tag{7}$$

**Table 1**
A good example of a stride

| | 1st and 2nd step [mm] | 2nd and 3rd step [mm] | Top of the jump [mm] |
|---|---|---|---|
| **1st** | 882 | 512 | 2477 |
| **2nd** | 842 | 486 | 2475 |
| **3rd** | 921 | 321 | 2450 |
| **4th** | 899 | 548 | 2476 |
| **5th** | 1011 | 520 | 2509 |
| **Avg.** | 911 | 477 | 2477 |

The angle of the spine is obtained by the angle between three points. First, vectors $\vec{a}$, $\vec{b}$ are obtained from the coordinates of the three points. The vectors are obtained as follows.

$$\vec{a} = (x_1 - x_2, y_1 - y_2, z_1 - z_2) \tag{8}$$

$$\vec{b} = (x_3 - x_2, y_3 - y_2, z_3 - z_2) \tag{9}$$

From these equations, the angle $\theta$ between the three points is obtained as follows.

$$\cos\theta = \frac{\vec{a} \cdot \vec{b}}{|\vec{a}||\vec{b}|} \tag{10}$$

## 3. Results

Tables 1, and 2 show the numerical values of the first and second stride lengths at the aid, the second and third stride lengths, and the height at each leap. In the best case, the average distance between the first and second steps was 911 mm, and the average difference between the second and third steps was 477 mm. In the bad case, the average distance between the first and second steps was 440 mm, and the average difference between the second and third steps was 690 mm. Thus, the difference between the two groups is 471 mm for the first and second steps and 213 mm for the second and third steps. The mean of the highest arrival point of the two cases is 2477 mm in the good case and 2290 mm in the bad case. Therefore, the difference between the two cases is 187 mm, which means that the maximum arrival point in the good case is higher than that in the bad case.

Tables 3 and 4 show the differences in the height of the highest point reached during the leap due to different backswing heights. The mean height of the right hand for the low backswing was 1028 mm, while the mean height of the right hand for the high backswing was 1302 mm. Thus, the difference in the mean height of the two backswings was 274 mm. The mean of the highest reaching point was 2448 mm for the low backswing and 2482 mm for the high backswing. Therefore, the difference in the mean of the highest point reached is 34 mm, and the highest point reached is higher in the case of the higher backswing.

Tables 5 and 6 show the angles of the spine extended and bent during the aid run and the highest point reached in the jump at that time. The average of the angles when the participants

**Table 2**
Bad example about a stride

| | 1st and 2nd step [mm] | 2nd and 3rd step [mm] | Top of the jump [mm] |
|---|---|---|---|
| **1st** | 428 | 777 | 2322 |
| **2nd** | 405 | 668 | 2326 |
| **3rd** | 510 | 669 | 2225 |
| **4th** | 455 | 728 | 2249 |
| **5th** | 400 | 607 | 2326 |
| **Avg.** | 440 | 690 | 2290 |

**Table 3**
A good example of the height of the backswing

| | Height of backswing [mm] | Top of the jump [mm] |
|---|---|---|
| **1st** | 1394 | 2488 |
| **2nd** | 1332 | 2491 |
| **3rd** | 1310 | 2464 |
| **4th** | 1251 | 2462 |
| **5th** | 1225 | 2506 |
| **Avg.** | 1302 | 2482 |

**Table 4**
Bad example about the height of the backswing

| | Height of backswing [mm] | Top of the jump [mm] |
|---|---|---|
| **1st** | 1001 | 2472 |
| **2nd** | 1097 | 2434 |
| **3rd** | 1067 | 2449 |
| **4th** | 977 | 2457 |
| **5th** | 999 | 2429 |
| **Avg.** | 1028 | 2448 |

were conscious of spinal extension was 170°, and the average of the angles when the participants were conscious of bending was 171°. Thus, the difference in the mean of the angles of the two spinal columns is 1°. The mean of the highest reaching point was 2408 mm in the case of the bent spine and 2456 mm in the case of the extended spine. Therefore, the mean difference of the highest point reached was 48 mm, and the highest point reached was higher when the participants were conscious of extending the spinal column.

**Table 5**
A good example of the angle of the spine

| | Angle of spine [°] | Top of the jump [mm] |
|---|---|---|
| **1st** | 172 | 2415 |
| **2nd** | 166 | 2454 |
| **3rd** | 170 | 2443 |
| **4th** | 174 | 2492 |
| **5th** | 172 | 2477 |
| **Avg.** | 171 | 2456 |

**Table 6**
Bad example about the angle of the spine

| | Angle of spine [°] | Top of the jump [mm] |
|---|---|---|
| **1st** | 169 | 2427 |
| **2nd** | 170 | 2428 |
| **3rd** | 173 | 2427 |
| **4th** | 168 | 2373 |
| **5th** | 170 | 2384 |
| **Avg.** | 170 | 2408 |

## 4. Discussion

The analysis of stride length revealed a substantial difference in the highest arrival point, indicating its paramount importance in spiking performance. Specifically, a difference of 187 mm was observed, underscoring the critical role of stride length. However, it is noteworthy that while the analysis solely focused on the distance between the heels of both feet, future investigations should consider the timing and speed of the stepping motion to provide a comprehensive understanding.

In examining the backswing, our analysis of joint coordinates successfully identified significant variations in backswing heights. This underscores the validity of the analysis method employed in our study, highlighting its potential for enhancing spiking techniques.

Contrastingly, the analysis of spinal column angle revealed no significant difference between the two angles, with only a 1° disparity noted. This suggests limitations in Azure Kinect's ability to accurately capture joint coordinates for the range of body movements evaluated in our study. Consequently, improvements in jumping motion may not be achievable through instructional interventions based solely on joint coordinate analysis using this methodology.

Moving forward, future research endeavors should explore alternative methodologies or technologies to overcome these limitations and further elucidate the intricacies of spiking techniques in volleyball.

## 5. Conclusion

In this study, Azure Kinect DK was utilized to capture joint coordinates during jumping motions in volleyball spikes, with a focus on stride length, backswing height, and spine angle. While analysis of joint coordinates for stride length and backswing height revealed differences between the two motions, examination of spinal column angle did not yield any significant disparities. Although it was anticipated that improvement in jumping motion could be achieved through analysis of joint coordinates for stride distance and backswing height, no significant difference was observed in spinal column angle. Consequently, it is inferred that this method may not effectively enhance jumping motion. Future research endeavors aim to expand sample size and explore alternative analysis methods.

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