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Using Clustering Algorithm to Validate the Golf Backswing Action Simulated by Microsoft Kinect Motion-Sensing Photography

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Abstract: While most golfers concern about the path that golf club travels on swing plane or the angle of the club face when addressing, rather the detrimental part may lie in golfer's body rotation. This research delineate a measure in capturing golfer's swing motions in which the Kinect motion tracking by Microsoft is adopted to validate the proposed measure. Subjects were hired to perform golf swings in front of the Kinect skeleton tracking system where subject's 20 joint positions were recorded. The derived data were analyzed with ANOVA and multivariate clustering. Without clustering, the three investigated factors (gender, age and experience) depicted no impacts on subject's swing performance. With the clustering, the differences were revealed in the light of the resulted two groups for distinguished characteristics. One group of less golfing experience which was mainly composed of female, younger and less golfing practice subjects achieved lower scores on swing correctness. Another group of experienced one which was with majority of male, senior and longer golfing tenure achieved higher swing scores. This research contributes in proposing an analysis framework that reveals the embedded information of golf swing motion. Implications for athletic practices were drawn accordingly.

Keywords: Skeleton tracking, golf swing, clustering algorithm, Kinect

1 Introduction

Originated in the 15th-century in Scotland, golfing is widely adopted in every cohort, making it a life-long activity and enjoyed by millions worldwide. The emergence of Tiger Woods boosted the game's popularity, turning it into a fashionable leisure activities. According to the Business Report of Sports Marketing Surveys, there are 61.1 million golfers worldwide. They are distributed mainly in the US (37.1 million), and the rests in Europe (6.9 million in), Asia (13.6 million), Australia (1.7 million), South America (1 million) and South Africa (0.5 million) [1]

The fascination of golf game lies in the challenge of its sophistication as well as golf course design. Players spend numerous hours in practicing, the swing in particular. The swing motion is subject to the coherence of player's body rotations. Golf swing detection as a result is a popular research subject in helping plyers to improve their swing techniques. To this end, the motion capture tracking software and motion capturing technology are often used to refine player's swing techniques in terms of biomechanics.

2 Golf swing motion analysis

There are several products, such as the Zepp, Swingbyte, Golf Coach, V1 Golf, and Swinguru, offering high-framerate, three-dimensional recordings and analysis for golf swings. Prior studies either adopt contact sensing method to obtain the swing information or use wearable sensor devices, including a triaxial accelerometer, gyroscope, and gravity accelerator, which are mounted on the golfer's limbs or relevant position. [2, 3, 4, 5, 6]

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Nevertheless, the physics of golf swing is deceptively more complicated than it appears, swinging a club to hit balls. Since the motions involve swinging a tool (the club) in which a successful swing depends on several sub-motions being properly aligned sequentially to allow club traveling up to the ball in line with the desired path. Golfers start with the non-dominant side of the body facing forwardly. At address, golfer's body and the centerline of the club face are positioned parallel to the desired line of travel, with the feet either perpendicular to the line or slightly splayed outward. Feet are commonly shoulder-width apart for middle irons and putters. After the addressing, backswing proceeds to get into position for hitting the ball. Figure 1 presents a set of graphics of eight sequential positions (from left to right): address, takeaway, halfway back, top, halfway down, impact, follow-through and finish. Each of these positions carries a unique skeleton joint. These uniqueness of joint positions and associated bone angles makes them ideal for tracking and analysis with Kinect motion-sensing photo equipment.

Lin *et al.* [7] uses Kinect sensor as a golf training system to detect six different types of commonly made mistakes in golf swings. Zhang *et al.* [8] adapts a Gaussian Mixture Model to create an automatic system where the Kinect sensor is applied in segmenting the golf swing to collect swing data. Shen *et al*. [9] uses the joint prediction output obtained by the Kinect sensor to enhance the predictability by benchmarking and cross-referencing the joint estimates with other motion-captured data. Somjarod *et al*. [10] propose the appropriate knee angle and direction of displacement by analyzing golfer's swing poses in videos. McHardy *et al*. [11] review the modern golf swing and contrast with Kinect motion tracking to the classic golf swing, to reduce golf injury, particularly the lower back injury.

3 Kinect motion-sensing photography

Image and geometry registration algorithms are essential components of many computer graphics and computer vision systems. With the technological advances in RGB sensors and motion tracking technology Microsoft Kinect becomes an active research tool. Sensing with a webcam-style add-on peripheral, Kinect enables users to control and interact with console without game controller. It is a more natural user interface of using gestures and spoken commands. Kinect sensor is composed of three lenses (Figure 2) including two optical sensors of an RGB color sensor and a near infra-red illuminator projector, and a depth sensor. The illuminator projects a pattern onto the room, and the color image is captured by the middle RGB color camera.

Kinect uses infra-red (IR) illuminator to obtain depth data, color images and sound, similar to the autofocus function of a digital camera. The core of Kinect's software lies in the skeleton recognition and body-tracking functions. As the RGB color camera and infrared CMOS camera are parallel, the color image and depth image captured overlap in a small area, that it, not completely coincident. The depth sensor consists of an infrared laser projector combined with a monochrome CMOS sensor that captures video data in 3D with respect to various ambient light conditions. The sensing range of the depth sensor is adjustable. The depth information is achieved by algorithm via the right camera and the leftmost infrared sensor which emit invisible laser beams [12].

Kinect exports video at a frame rate of 9 Hz to 30 Hz depending on resolution. Per monochrome depth sensing, the video stream is in VGA resolution at 640*480 pixels with 11-bit depth, providing 2,048 levels of sensitivity. Kinect enables a practical ranging limit of 1.2-3.5 meters with an angular view field of 57X horizontally and 43X vertically. The motorized pivot enables tilting the sensor up to 27X upward and downward. The minimum viewing distance of Kinect is 87 cm and the vertical field is 63 cm that results in a resolution of 1.3 mm per pixel. In the light of software, Kinect interprets gestures completely hands-free of electronic devices possible. It uses an infrared projector, camera and a specialized microchip to track the movement of objects in three dimensions (Figure 3).

Kinect's coordinating system is centered on the sensor and attaches the origin to the positive z-axis extending in the direction the sensor aiming at. The positive y-axis extends upward and the positive x-axis to the left. Per skeleton tracking purpose, Kinect updates every skeleton frame which contains a floor-clipping-plane vector. That clipping plane helps to remove the background to segment frames of golfers. The following equation depicts this concept:

$$Ax + By + Cz + D = 0$$

where:

$$A = vFloorClipPlane.x$$

$$B = vFloorClipPlane.y$$

$$C = vFloorClipPlane.z$$

$$D = vFloorClipPlane.w$$

4 Experiment design

We use Kinect SDK (Software Development Kit) to convert the depth image data into the human skeleton structure. The SDK supports several languages for programming, including JavaScript, C#, C++ and VB. The grand system is composed of the skeleton tracking system, voice recognition, face tracking, and 3D scan. The skeleton tracking system tracks data of skeletons in the field of viewing, consisting of 3D positions of 20 joints with the coordinates of X, Y and Z (Figure 4). As the refresh frequency is 30 frames per second, there will be a 33ms error time between joints per action [13].

When subject performs a swing in front of the Kinect, he or she will be asked holding a specific gesture for a few seconds. This may be a drawback for practicing since swing is to derive a free flow of the body rotation as well as the club. Per experiment, it starts with a backswing to the top clockwise from the X reference point. Feet width is set to the width of shoulders typically. For a right-handed golfer, swing is then to make clubhead traveling sequentially as follows.

(1)Address
Golfer sets in the middles of feet where the target-side (left) foot flaring toward the target between 20 and 40 degrees, and the back (right) foot keeps square (90 degrees to the target line). The slightly open of left foot enables following through the golf swing smoothly. The knees flex slightly for balance during the swing. The center of the upper spine (between the shoulder blades) knees and balls are aligned on the target line. In addition, golfer's upper torso needs to lean forward slightly from the waist with slightly bending of the knees allowing flexibility. Besides, the body bends at the hips where the spine is the axis of rotation for the swing. Player bends toward the ball at approximately a 90-degree angle to the shaft of the club. Both the left-side hip and shoulder are slightly higher than the right-side and keeps the entire pelvis facing the target. Player's chin is up so that the left side of face is in line with the ball and the club is set to face the target.

(i)Judgment 1: left shoulder higher than right shoulder
The SHOULDER_LEFT and SHOULDER_RIGHT joints provided by Microsoft Kinect human joints are used for detection. When the Y value of SHOULDER_LEFT is smaller than the Y value of SHOULDER_RIGHT, it means the player's left shoulder is lower than right shoulder. The discriminant is expressed as Eq. (i).

$$If(Y_{SHOULDER\_LEFT} - Y_{SHOULDER\_RIGHT}) \geq TH_1,$$

$$EP_1 = 1,$$

Otherwise

$$EP_1 = 0 \qquad \text{(Eq. (i))}$$

*where TH_1 is the system set threshold

(ii)Judgment 2: spacing between feet
In terms of golf swing stance, the width between the feet shall be identical with the shoulder width. The SHOULDER_LEFT, SHOULDER_RIGHT, FOOT_LEFT, and FOOT_RIGHT joints provided by Microsoft Kinect human joints are used for detection. When the distance between the X value of FOOT_RIGHT and the X value of FOOT_LEFT is greater than the distance between the X value of SHOULDER_RIGHT and the X value of SHOULDER_LEFT, it means the player's stance is too wide. The discriminant is expressed as Eq. (ii).

$$If(Distant_{FL}^{FR} - Distant_{SL}^{SR}) \geq TH_2,$$

$$EP_2 = 0,$$

Otherwise

$$EP_2 = 1 \qquad \text{(Eq. (ii))}$$

$Distant_{FL}^{FR} = |X_{FOOT\_Right} - X_{FOOT\_LEFT}|$ (feet width)
$Distant_{SL}^{SR} = |X_{SHOULDER_Right} - X_{SHOULDER_LEFT}|$ (shoulder widt) *where TH_2 is the system set threshold.

(2)Takeaway and Halfway back Golfer's right arm stays close to the chest. Right shoulder turns higher than left shoulder. When hands pass right leg player's gravity center starts shifting to the right in which the club travels parallel to the ground and continue to the target line. During the gravity center moving, the momentum of the swing and the folding of right elbow collaborate to hinge the club in a 90-degree angle on left arm leaving left arm slightly higher than right arm. When parallels to the target line the club is ready to move around body that brings shoulders into rotation by pulling hips into the swing.

(i)Judgment 3: right shoulder higher than left shoulder The correlation among the SHOULDER_LEFT, SHOULDER_RIGHT, SHOULDER_CENTER, and HIP_CENTER joints provided by Kinect human joints is used for judgment. The discriminant is expressed as Eq. (iii).

$$If|Y_{SHOULDER\_RIGHT} - Y_{SHOULDER\_LEFT}| \geq TH_{31}$$

AND

$$|X_{SHOULDER\_CENTER} - XHIP\_CENTER| \geq TH_{32}$$

$$EP_4 = 0,$$

Otherwise

$$EP_3 = 1 \qquad \text{(Eq. (iii))}$$

*where TH_{31} and TH_{32} are the system set threshold.

(ii)Judgment 4: whether right elbow is raised or not
The correlation among the SHOULDER_RIGHT, ELBER_RIGHT, and HAND_RIGHT joints provided by Kinect human joints is used for

Table 1: Chi-square test for independent variables on the correct swings

		Value	df	Asymp.Sig. 2-sided	significance
Gender	**Pearson Chi-Square**	3.404*	3	0.333	
	Likelihood Ratio	4.004	3	0.261	
	Linear-by-Linear Association	0.405	1	0.524	
Age	**Pearson Chi-Square**	25.994**	15	0.338	***
	Likelihood Ratio	23.586	15	0.072	
	Linear-by-Linear Association	2.833	1	0.092	
Experience (years)	**Pearson Chi-Square**	10.958**	15	0.756	
	Likelihood Ratio	10.402	15	0.794	
	Linear-by-Linear Association	2.886	1	0.089	
	N of Valid Cases	21			

* 7 cells (87.5%) have expected count less than 5. The minimum expected count is 0.33.

** 24 cells (100.0%) have expected count less than 5.The minimum expected count is 0.05.

*** means that it is significant under 5% significance level.:

judgment. The discriminant is expressed as Eq. (vi).

$$If|Y_{SHOULDER\_RIGHT} - Y_{ELBER\_RIGHT}| < TH_{41}$$

AND

$$|Y_{HAND\_RIGHT} - Y_{ELBER\_RIGHT}| < TH_{42},$$

$$EP4 = 1,$$

Otherwise

$$EP4 = 0 \qquad \text{(Eq. (vi))}$$

*where TH_{42} is the system set threshold.

(3)Top

On top of the backswing, wrists are fully hinged at halfway back and hips turn as far as the shoulders. In addition, the left arm remains straight with right elbow points to the ground.

(i)Judgment 5: backswing

The Y-axis difference value of SHOULDER_CENTER joint provided by Kinect human joints in the swing process from backswing starting point to the top of backswing is used for judgment. The discriminant is expressed as Eq. (iv).

$$If(Y_{start} - Y_{end}) \geq TH_{51},$$

$$EP_5 = 1,$$

Otherwise

$$EP_5 = 0 \qquad \text{(Eq. (iv))}$$

*where TH_{51} is the system set threshold.

(ii)Judgment 6: backswing amplitude

The body shifts if the backswing amplitude is too large; the X value of SHOULDER_CENTER and HIP_CENTER joints provided by Kinect human joints is used for judgment. The discriminant is expressed as Eq. (v).

$$If|Y_{SHOULDER\_CENTER} - Y_{HIP\_CENTER}| < TH_{61},$$

$$EP_6 = 1,$$

Otherwise

$$EP_6 = 0 \qquad \text{(Eq. (v))}$$

*where TH_{61} is the system set threshold.

5 Clustering algorithm validation

This study invited 21 golfers (14 males and 7 females) of a golf club to participate in the experiment, following the gender ratio of Wang *et al.* [14]. After a brief of the experiment, subjects were asked to stand within a sensible range of the Kinect. The experiment began when the golfer was detected by the system.

5.1 Chi-Square Tests

19 golfers were judging with correct postures by meeting the following Judgements: firstly, they addressed with left shoulder higher than right shoulder (Judgment 1); secondly, the width between the feet is identical with the shoulder width (Judgment 2); thirdly, in the mid of backswing, golfer's right elbow didn't raised up (Judgment 4). Additional judgement (Judgment 6) was

Table 2: Grouping with clustering

Subject	Percentage	Cluster	Distance
1	67%	1	0.976
2	83%	1	0.839
3	83%	1	0.976
4	83%	2	0.746
5	100%	1	1.484
6	83%	2	0.843
7	100%	1	1.398
8	83%	2	0.746
9	100%	2	0.414
10	83%	1	0.673
11	100%	2	1.420
12	83%	1	0.839
13	83%	2	0.843
14	83%	2	1.906
15	100%	2	2.437
16	50%	1	1.097
17	83%	2	1.906
18	83%	1	0.673
19	100%	2	1.420
20	83%	2	2.437
21	83%	2	1.575

included for it may cause lower back injuries [15]. There were 5 subjects having their body shifts backswing amplitude too far.

By testing the correct swings with respect to the gender, age and experience factors, only the age is a significant factor. It implies that the age factor is positively associated with correct swing motions (Table 1).

5.2 Subjects clustering

The insignificance above hinders our investigation regarding experimental factors. To reveal the relationships, we try to group our subjects by multivariate clustering analysis and redo ANOVA. By applying cluster analysis on the observations, it resulted into two groups: 9 golfers in group 1, including subject 1,2,3,5,7,10,12,16 and 18, and 12 golfers group 2, including subject 4,6,8,9,11,13,14,15,17,19, 20, and 21 (Table 2).

Group 1 was mainly composed of female with 1-5 years of golf experience, and 20-29 years old of age. Group 2 was mainly of male with 15-20 years of golf experience, and in 40-49 years old of age (Table 3).

Table 4 depicts the results of analysis of variance (ANOVA) on derived groups. Via clustering, the three experimental factors become significant in telling the difference among golf players. For the gender factor, the respected p_value is 0.066. Per age, the p_value is 0.000 and experience is 0.000. This result is more close to our conjectures where the golf player could deliver the proficiency of golf swings subject to his/her age, gender and experience.

Table 3: Characteristics of groups

	Cluster	
group	1	2
gender	Female	Male
experience (years of golf playing)	1-5	15-20
age	20 29	40-49

Not surprisingly, the male players depict a superior physical advantages over female players. Same for the experience factor. More practice may arrive better performance. Interestingly, the age factor however implies the concordance of body and mentality. Younger players may have stronger physical advantages however may be out of control, say, swing too hard. The middle age players may swing with just enough force to get a superior result.

6 Conclusion

In the light of swing as the core element of golfing, swing detection is therefore a popular research subject as well as in practice. Motion tracking becomes a useful tool to refine player's swing techniques in terms of biomechanical perspective. This research adopts the Kinect motion tracking system to propose a tracking system for golf players to improve their swing motions. Several judgments regarding the swing motion are proposed to obtain player's swing data. The data were coded into information for feedback to enhance player's swing. To test the performance of the system, we hired 21 golfers of different gender, age and experience of golf playing to participate the swing experiment. The experiment is designed according to typical swing procedure in eight positions: address, takeaway, halfway back, top, halfway down, impact, follow-through and finish. Each of these positions has its own skeleton joint to track, that makes them ideal for record and analysis with Kinect motion-sensing photo equipment. Five modeling equations were adopted to represent the measures of the obtained data via Kinect. The derived data were analyzed with ANOVA and multivariate clustering. Without the clustering on subjects, the three factors (gender, age and experience) were shown no impacts on subject's performance in swing. Strikingly, after the clustering, the differences were revealed. According to the analysis on the clustered subjects, the male players depict a superior physical advantages over female players. Same for the experience factor, in which more practice renders in better performance. Interestingly, younger players may have stronger physical advantages however may overswing. The middle age players may swing more smoothly to get a superior result. In other

Table 4: ANOVA results

	Cluster		Error				
	Mean Square	df	Mean Square	df	F	Sig.	note
gender	0.778	1	0.205	19	3.800	0.066	*
age	30.730	1	0.713	19	43.073	0.000	**
experience	26.683	1	1.047	19	25.490	0.000	***

* means that it is significant at 10H significance level;

** at 5%;

*** at 1%.

words a superior synchronization of body and mentality delivers greater swing performance.

This research contributes in proposing an analysis framework to reveal the embedded information of golf player's swing motions derived from the Kinect tracking system. Furthermore, the application of the multivariate clustering on subjects with respect to the appropriate factors, the embedded information is better revealed with respect to player's personal situation that improves the capability in helping players to improve. Secondly, this study shows a robust feedback method for golf players in improving their swing motions. By measuring with the provided five modeling equations, the eight sequential positions in swing are each well-presented that may help users following through the swing motion to check the defects inside.

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