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Feedback of Flying Disc Throw with Kinect: Improved Experiment

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Abstract: This paper shows an improved experiment result of a feedback system for flying disc learners with use of Kinect device. Compared with conventional 3-D motion capture systems, Kinect has advantages of cost, easy system development and operation. Our formerly proposed system in Yamaoka (2013) captures learners' specific 20 points in 3-D manner, judges their postures and motions based on criteria defined by a domain expert, and displays feedback messages to improve their motions. An improved experiment increases the time of flying disc throw in pre-test (10 to 30) and test (5 to 10). This change allows testees to be accustomed with disc throwing activity in experimental environment, and also to master given feedback message. As a result, relatively novice testees of the target group showed significant improvement of their throwing motions.

Keywords: Flying disc, throwing movement, Kinect, capture, feedback

1. Introduction

In the field of sports science research, kinematic analysis of human body became popular in the last decade. Barris (2008) surveyed vision-based motion analysis researches for sports. Moeslund (2006) surveyed vision-based human motion capture / analysis systems. Miles (2012) surveyed applications of Virtual Reality environments for ball sports. There are wide variety of equipments adopted in these researches: GPS sensor, acceleration sensor, muscle sensor, HMD (Head Mound Display) etc. Among them, the major equipments are so called "motion capture systems", that measure many points of human body in three-dimensional space. Also the systems archive 3-D information along timeline. However, the major motion capture systems are extremely expensive, costing several hundred thousand dollars. Additionally, they require dedicated rooms, multiple cameras, special lighting capacity and dedicated "tracking suits" to specify a tracking points of human body. Furthermore, myriad steps are necessary to set up and data acquisition including the activity called "calibration", which adjusts the 3-D points of marking sensors on the tracking suit. As a result, this kind of analysis is infrequently performed outside of specialized research or specific studies of top athletes.

In contrast, Kinect device released by Microsoft Corporation in 2010 offers a simple and inexpensive way to perform 3-D analysis of a human body movement. First, the device itself costs only U.S.$110, which is far cheaper than conventional motion capture systems. Second, Kinect is capable of capturing data easily. It does not need any tracking suits nor complex set-up and operation procedure for data acquisition. Third, Microsoft has publicly released a software development kit (SDK) that includes the necessary library for data acquisition using Kinect. Application system developers are able to write customized Windows applications with use of this library in the C# or C++ languages.

The proposed research in this paper has 3 major points below:

(1) Utilizes Kinect

(2) Captures 3-D motion and give feedback to sports learners

(3) Target motion: flying disc throw

There are many preceding researches to analyze human body motion with use of motion capture systems including Kinect. Also, there are some researches to give automatic feedback messages to learners to refine their motion. The authors arranged these researches as shown in Table 1 in order to survey categories (1) and (2).

Table 1: Preceding researches

	Analysis	Feedback
Commercial/ Original 3D Motion CaptureSystem	Bideau (2004) Brodie (2008) Corazza (2006) Hachimura (2004)	Ishii (2011) Kwon (2005) Soga (2008)
Microsoft Kinect	Fujimoto (2012) Hsu (2011) Kato (2012) Marquardt (2012) Mitchell (2011) Ogawa (2012)	Chye (2012)

Papers at upper left side in Table 1 utilize commercial or original 3D motion capture systems to analyze 3-D motion. Bideau (2004) utilized Vicon 370 system to analyze relationship of movement between throwers and a goalkeeper of handball. Brodie (2008) synthesized a body model of a ski racer from GPS information and video motion graphics. Corazza (2006) synthesized a body model with use of 8 motion cameras and replays it in a virtual environment. Hachimura (2004) developed a dance training support system with use of magnetic sensor system Fastrak and HMD.

At upper right side, there are researches to give feedback messages to learners, based on 3-D captured data. Ishii (2011) utilized a motion capture system IGS-190 for baseball batting movement. It also provided a comparing function between “goal motion” and learner’s one. Based on the comparison, the system showed messages to refine learner’s motion. Kwon (2005) developed an original motion capture system for Taekwondo training. It also displayed a visual feedback to adjust one’s movement. Soga (2008) proposed a training support system for rhythmic gymnastics. It adopted an optical motion capture system, compared the captured data and ideal motion data, and displayed feedback messages in the screen.

At lower left side in Table 1, there are researches to analyze human motion with use of Kinect. Fujimoto (2012) developed a dance training support system. It showed learner’s image and instructor’s ideal motion image in overlaying manner. Hsu (2011) discussed many possibilities of Kinect utilization in various sports learning activities. Kato (2012) developed a system to compare a professional player and a novice learner of soccer. Marquardt (2012) diagnosed a pose of ballet dancer with use of Kinect. It is called “Super Mirror”, because common ballet studios use a mirror to check and adjust one’s pose. Mitchell (2011) developed a Kinect based system to diagnose hand movement for playground game. Ogawa (2012) developed a distance learning system. An instructor and a learner share a common virtual space, and compare their body motions.

Finally, at the lower right side, there is one preceding research similar to the proposing method. Chye (2012) utilized Kinect to diagnose Karate pose. He compared 4 joint points of an instructor and a learner, calculated their Euclid distances, and gave feedback messages to the learner.

As mentioned in the third point written above, this research focuses on the motion of flying disc throw. The authors have previously published research on the movement itself (Shima 1992, 1994, 1996, 2000). Also the authors applied these results to actual physical education tasks through the development of multimedia teaching materials (Shima 2002, 2004). Beyond them, Sasakawa (2011) analyzed the throwing motion, while Koyanagi (2010) formularized the characteristics of the applicable movement with use of a disc with an inertial sensor. Murayama (2006) conducted research on guidance using an instantaneous feedback system, while Takeuchi (2010) conducted analysis with use of a motion capture system.

This paper proposes a real time, 3-D motion capture and feedback system using Kinect, which targets novice learners to throw a flying disc. The system allows the learners to observe their own movements through video playback in real time. Also it diagnoses their joint movement and gives feedback messages automatically on their throwing form. Practiced use of the proposed system will give learners a visceral grasp of the correct throwing form, which will in turn lead to improved accuracy of throwing performance. In addition, if employed as part of physical education instruction, it is expected that the system will aid instructors in providing individualized critique to learners and will contribute to the efficiency of the instructional environment.

2. Proposed System

The proposed system will process data in three steps: (a) acquisition of 2-D video images and position data for each point; (b) assessment of whether the flying disc throwing movement is correct or incorrect based on the Position data acquired for each point; and (c) display of feedback messages with 2-D motion images from (a) based on the results of the assessment in (b). Details of each process step are given below.

2.1 Kinect and its Data Acquisition

Kinect is a device with a function to analyze the motion of human subjects in 3-D manner. It was initially developed as a peripheral device to be connected to Microsoft's Xbox gaming system. Kinect includes a CMOS camera, infrared projector, image depth sensor, microphone, and one USB port for connection to a Windows PC. Kinect projects patterned infrared rays that are analyzed by its CMOS camera to recognize the distance between the player and the device. Also, through the machine learning function called "human pose estimation" developed by Microsoft Research Cambridge, Kinect is able to recognize the positions of subjects' joints with reasonable accuracy. The coordinates of each point detected by Kinect can be read into a Windows PC using the library included in the device's SDK.

In order to acquire Kinect data, called "SkeletonStream" properties in the Kinect SDK library must be enabled. The coordinate data for each point is extracted from the data structure called "Kinect.JointType", which is also available in the library. Point coordinate data values can be used to measure one's motion in real time.

2.2 Assessment of Throwing Form

This paper is interested in the assessment of flying disc throw movement. However, the skill levels of learners are hugely diverse, with intermediate learners and above representing the most difficult subjects to biomechanically assess. Consequently, this study focused on absolute beginners and made assessments by comparing whether or not their throws matched a basic standard throwing motion.

When processing the assessments, the throwing movement was divided into the three phases: pre-motion (take back), motion (swing), and post-motion (release). Assuming a right-handed thrower, the phase is judged by the following equations.

Take back: $x11 < x2$ (1)

Swing: $x2 <= x11 < x9$ (2)

Release: $x9 <= x11$ (3)

These numbers of 2, 9, or 11 are the identifiers of specific body parts defined by Microsoft Kinect, shown in Figure 1. Also, 'X' represents horizontal coordinates, with movement in the direction of the right hand receiving a positive value. In the pre-motion phase, the take back phase, the thrower's right hand is left of the body's center; in the motion phase, the thrower's right hand is between the body's center and the elbow; and in the post-motion phase, the finish, the thrower's right hand is to the right of the right elbow. Figure 2 shows graphics of these three phases.

Next, assessments contain next five aspects: (a) enough take back (before the throw), (b) adequate height of the right hand, (c) height transition of the right hand, (d) adequate angle of the right elbow, and (e) enough twisting of the waist.

The aspect (a) is judged whether the movement contains the take back phase before the swing phase. A novice thrower tends to have insufficient take back and have a throwing motion like a ring toss. In order to prevent this error, the thrower should have a proper take back motion before the throw.

The aspect (b) is relevant to all phases of the throw. It assesses whether the right hand is properly below the level of the shoulder but above the solar plexus. The judgment is expressed by equation (4). Novices tend to allow their right hand to rise above their shoulder.

Hence this assessment is effective for spotting this error.

$$y1 < y11 < y2 \qquad (4)$$

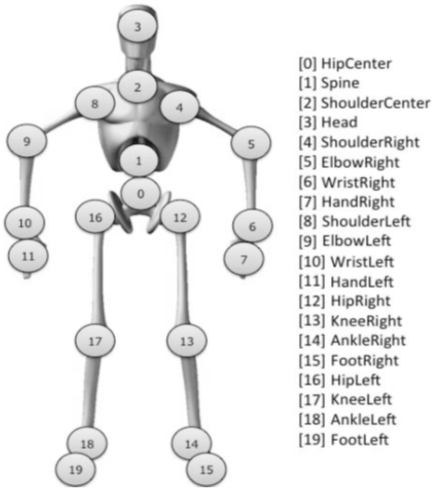

Figure 1: Numbers of Body Parts

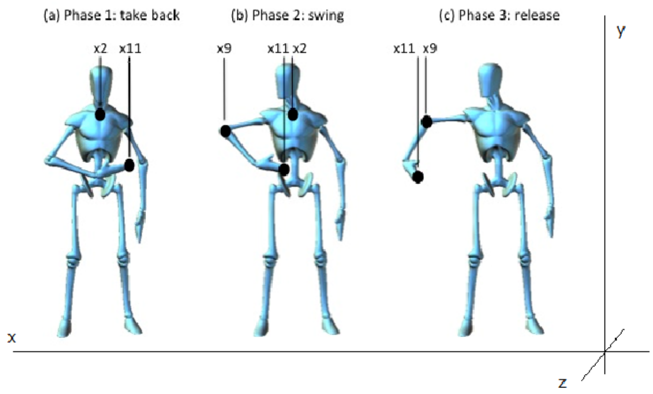

Figure 2: Phase of the Throw

'Y' represents vertical coordinates. The aspect (c) is similar to (b) and assesses movement patterns that tend to prevent the disc from flying parallel to the ground, such as a throw that bows upward or downward, or a throw that swings upward. In concrete terms, if the position of the right hand is analyzed for each phase, the following judgments can be made as equations (5)-(7). Here "Low" means $y11 < y1$, "OK" means $y1 <= y11 < y2$, and "High" means $y11 >= y2$, while "y1" means height of "Spine", numbered part in Figure 1.

Bowing upward: (OK or Low in take back) & (High in swing) & (OK or Low in release) (5)
Bowing downward: (OK or High in take back) & (Low in swing) & (OK or High in release) (6)
Swinging: (Low in take back) & (High in release) (7)

The aspect (d) assesses whether the angle made by the right shoulder, right elbow, and right wrist is 120 degrees or greater during the swing phase. Some novices tend to fully extend their arm when throwing the disc, causing them to lose the angle of the elbow that helps produce speed and spin.

The aspect (e) assesses whether there is sufficient twist in the waist during the take back phase. In the x-z planes, tangents for the right and left foot vector (14, 18) and waist vector (12, 16) are calculated. Specifically, the following conditional equations (8)-(10) are used.

$$m1 = (z14-z18)/(x14-x18) \qquad (8)$$
$$m2 = (z12-z16)/(x12-x16) \qquad (9)$$
$$\text{if } (m2-m1)/(1+m1m2) <= -10 \text{ deg then OK} \qquad (10)$$

'Z' represents deep direction and the numbers show the parts in Figure 1. Under the current assessment approach, the conditions are set to require the above vectors to be parallel (that is, the above discriminant = 0).

2.3 Implementation

The proposing functions were implemented with use of (1) Windows PC, (2) Microsoft Official SDK (software development kit) for Kinect, and (3) Kinect device for Windows. Figure 3 shows an example screenshot of the developed system. A thrower is able to receive feedback of his throwing motion. Currently it is real time feedback, so the system is unable to play back thrower' motion later. It may cause less effect for the feedback. This playback feature is one of the future issues.

3. Experiment

In order to verify the effectiveness of the proposing system described above, the authors performed a control experiment. As stated above, this paper shows an improved experiment rather than shown in Yamaoka (2013). The major improvement is the time of flying disc throw: 10 to 30 for pre-test, and 5 to 10 for test. This change allows testees to be accustomed with disc throwing activity in experimental environment, and also to master given feedback message.

3.1 Preparation

In order to measure the preciseness of the throw, the authors prepared a large and lightweight fabric of 4m x 8m, on that 50cm wise grids were drawn. Furthermore, the target mark was drawn at the horizontal center and 1.5m up from the bottom of the fabric. This fabric was used (1) to measure the preciseness of the throw, with use of drawing grid, and (2) to project the screen of the proposed system as in Figure 3. The experiment was prepared to hang this fabric on the wall of a gymnastic hall of the university. Figure 4 shows scenery of the experiment.

The authors adopted two types of measurements. One is testee's movement with use of the proposing system. As stated in section 2.2, it has 5 aspects of qualitative assessments. In order to do it, the developed system on Windows PC, Kinect device, and LCD display were settled. The other is precision. It is measured how near a disc hits from the target mark drawn on the fabric, 7 meters from a testee. Quantitatively, a staff checked a hit point of the disc, measured both vertical and horizontal distances from the target mark, and calculated the distance from the mark.

There are two requirements for the place of the experiment: indoor place to avoid wild weather, and electronic supply nearby. In order to satisfy these conditions, the experiment was done at the central gymnastic hall of Sophia University on 24-31 July 2013. Testees were 40 undergraduate students of Sophia University, and all of them were novice learners of flying disc throw.

3.2 Procedure

First, as a pre-test, all 40 testees were examined the precision of the throws. They threw 30 flying discs to hit the target mark on the fabric. Grades (movement and precision) of all testees were measured. Next, the testees were divided into 2 groups of 20 members, which were statistically insignificant. In the pre-test, the proposing system was used to measure testees' movements, but no feedback was given to

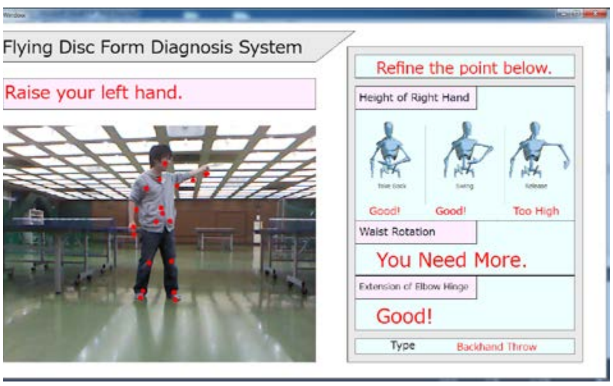

Figure 3: Sample Screenshot

Figure 4: Scenery of Experiment

testees.

Next, as a test, the target group (TG) members were given feedback in 10 times of throwing movement with use of the proposing system. As shown in Figure 4, a testee saw the visual feedback on the LCD display during throwing movement. On the other hand, the control group (CG) members had no feedback from the proposing system.

The “improvement” is to increase throwing times, 10 to 30 for pre-test and 5 to 10 for test. The last experiment didn’t show any significance, and the authors supposes the reason on insufficient feedback of throwing. Also, increase of pre-test contributes to show more precise skill level of each testee.

3.3 Result

First, whole TG (20 members) and whole CG (20 members) were compared by measure of movement, captured by Kinect. The grade is the summation of 5 criteria. The result is shown in Table 2. Based on the result, the proposing system does not effect in the feedback of testees’ motion in significance level of 5%.

In order to check the detail, the authors drew graphs of both TG and CG, that show scores of pre-test and test to arrange pre-test score in descending order. Figure 5 shows it for TG, while Figure 6 for CG. In these figures, X axes are for testee sequence, while Y axes for grades in full of 100 (each 20 points for 5 aspects (a)-(e) in Section 2.2). In Figure 5, top level testees (arranged in the left side) have no significant improvement of test scores compared with pre-test. It might mean that non-novice (intermediate) learners are not effective with use of the proposing feedback system. Based on this hypothesis, another comparison was made to omit top 5 testees of both TG and CG. In other words, comparison was made with 15 testees of both TG and CG. This result is shown in Table 3. Table 3 shows statistical significance (3.04%) in significance level of 5%. From this result, the proposing system is effective of disc throw motion improvement in relatively novice learners.

4. Discussion

While the authors are discussing the system functions and assessment criteria shown in the Section 2.2, there are some arguments below.

- Further patterns are possible in regards to the formula used for assessment aspect (c) and judgment of a throw as “bowing upward,” etc. It is necessary to add additional throwing patterns, acceptable ones and clearly erroneous ones, as we gather measurements from further experiments.
- Assessments aspects (d) and (e), judging the angle of the right elbow and the twist of the waist, respectively, are still at a trial stage. It is necessary to consider and debate their validity
- in light of actual throwing movements.
- Assessment aspect (e), twisting of the waist, currently is calibrated for ‘0’ waist twist even during the take back phase, which means that parallel waist and feet receive a positive assessment. Other options exist, though, such as a negative value indicating twisting of the waist.
- Currently, the feedback to the learner is given in text only. Adding audio and voice functionality will likely make the feedback more readily apparent to the learner.
- The proposing system does not treat moving speed of critical body parts. Currently it is out of focus in measurement and feedback, but should be included in the future work.

The result of experiment shows significance only for relatively novice learners. It means that there are some other feedback criteria for intermediate learners. This point is thought as one of the future issues.

5. Conclusion

This paper has presented a system with use of Kinect device for analysis of and feedback on the motion of throwing a flying disc. A result of experiment shows that this method is useful for relatively novice learners to improve their movement. Future research will work to refine the current system vis-à-vis the points noted in Section 4, and retry to validate the efficiency of the proposing system with improved methods and sequence.

Table 2: Result of t-test (1)

	TG	CG
Mean	74.14	63.82
Variance	208.2993684	350.9764211
Observations	20	20
t Stat	1.951558999	
P(T<=t) One Tail	0.029195101	
t Critical One Tail	1.304230204	
P(T<=t) Two Tail	0.058390202	
t Critical Two Tail	1.68595446	

Table 3: Result of t-test (2)

	TG (low 15)	CG (low 15)
Mean	71.17333333	58.21333333
Variance	207.6335238	276.9740952
Observations	15	15
t Stat	2.280108492	
P(T<=t) One Tail	0.015208549	
t Critical One Tail	1.701130934	
P(T<=t) Two Tail	0.030417098	
t Critical Two Tail	2.048407142	

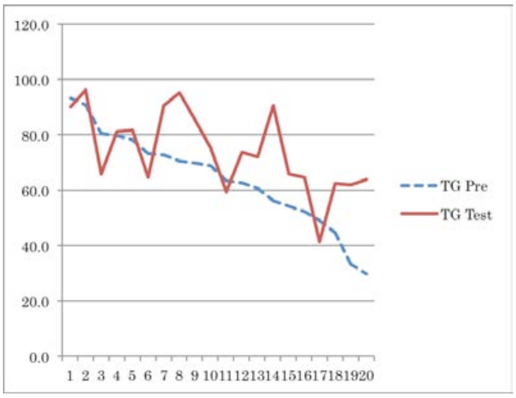

Figure 5: Ranking of Target Group

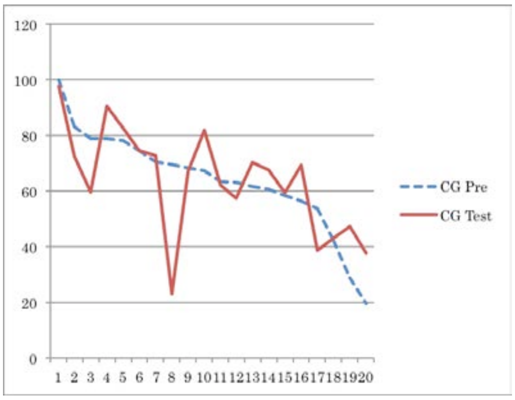

Figure 6: Ranking of Control Group

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