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Feedback of Flying Disc Throw with Kinect and its Evaluation

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Abstract

This paper proposes a three-dimensional motion capture and feedback system for flying disc learners with use of Kinect device. Compared with conventional 3-D motion capture systems, Kinect has advantages of cost merit, easy system development and operation. The proposing system captures learners' body movement, checks their skeleton positions in pre-motion / motion / post-motion in several aspects, and displays feedback messages to improve their motions. A novice learner of flying disc is trained to keep arm movement in steady height, to twist the waist, and to stretch the elbow according to the waist angle. A result of controlled experiment shows that the proposing system is effective for beginners to improve their movements.

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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 [1] surveyed vision-based motion analysis researches for sports. Moeslund [2] surveyed vision-based human motion capture / analysis systems. Miles [3] 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

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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 [4], Brodie [5] Corazza [6], Hachimura [7]	Ishii [8] Kwon [9] Soga [10]
Microsoft Kinect	Fujimoto [11], Hsu [12], Kato [13], Marquardt [14], Mitchell [15], Ogawa [16]	Chye [17]

Papers at upper left side in Table 1 utilize commercial or original 3D motion capture systems to analyze 3-D motion. Bideau [4] utilized Vicon 370 system to analyze relationship of movement between throwers and a goalkeeper of handball. Brodie [5] synthesized a body model of a ski racer from GPS information and video motion graphics. Corazza [6] synthesized a body model with use of 8 motion cameras and replays it in a virtual environment. Hachimura [7] 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 [8] 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 [9] developed an original motion capture system for Taekwondo training. It also displayed a visual feedback to adjust one’s movement. Soga [10] 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 [11] developed a dance training support system. It showed learner’s image and instructor’s ideal motion image in overlaying manner. Hsu [12] discussed many possibilities of Kinect utilization in various sports learning activities. Kato [13] developed a system to compare a professional player and a novice learner of soccer. Marquardt [14] 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 [15] developed a Kinect based system to diagnose hand movement for playground game. Ogawa [16] 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 [17] utilized Kinect to diagnose Karate pose. He compared 4 joint points of an instructor and a learner, calculates their Euclid distances, and gives 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 [18]-[22]. Also the authors applied these results to actual physical education tasks through the development of multimedia teaching materials [23] [24]. Beyond them, Sasakawa [25] analyzed the throwing motion, while Koyanagi [26] formularized the characteristics of the applicable movement with use of a disc with an inertial sensor. Murayama [27] conducted research on guidance using an instantaneous feedback system, while Takeuchi [28] 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. Features of Kinect

Kinect is a device that is able to analyze the motion of human subjects in three dimensions. Initially developed as a peripheral apparatus to be connected to Microsoft’s Xbox gaming system, Kinect includes a CMOS camera, infrared projector, image depth sensor, microphone, and a 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. Figure 1 shows 20 recognizable points by Kinect (Microsoft calls them “skeleton positions”).

The coordinates of each point detected by Kinect can be read into a Windows PC using the library included in the device’s SDK. There are two types of coordinates.

(1) Point: coordinates of the joints on a two-dimensional video image acquired by the camera. They are displayed as 2-D (x,y) coordinates. Image resolution and frame rate options are as follows.

(2) Position: 3-D coordinates (x,y,z) of the points in a virtual 3-D space.

Both coordinates are recorded and represented in three ways of pixels and frames below.

- 640 x 480 x 15 frame
- 640 x 480 x 30 frame
- 1280 x 960 x 12 frame

3. Proposed System

This paper proposes a system that 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.

3.1. Acquisition of Kinect Data

The "SkeletonStream" properties in the Kinect library must be enabled in order to acquire Kinect data. Similarly, the coordinate data for each point must be extracted from the data embedded in the "Kinect.JointType" category structure, which is also available in the library. Point coordinate data values can be used to assess motion in real time.

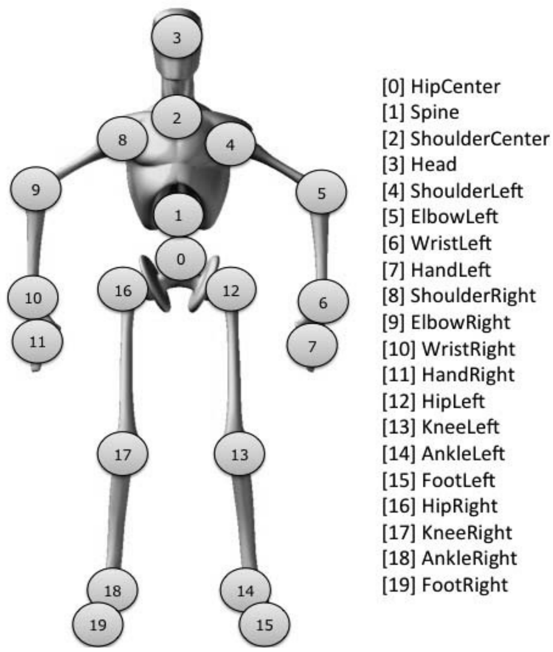

Fig. 1 Joints Recognizable with Kinect

3.2. 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.

$$\text{Take back:} \quad x11 < x2 \tag{1}$$

$$\text{Swing:} \quad x2 <= x11 < x9 \tag{2}$$

$$\text{Release:} \quad x9 <= x11 \tag{3}$$

These numbers are the point numbers from Fig. 1. '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. Fig. 2 shows graphics of these three phases.

Next, assessments contains 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 formula (4). Novices tend to allow their right hand to rise above their shoulder.

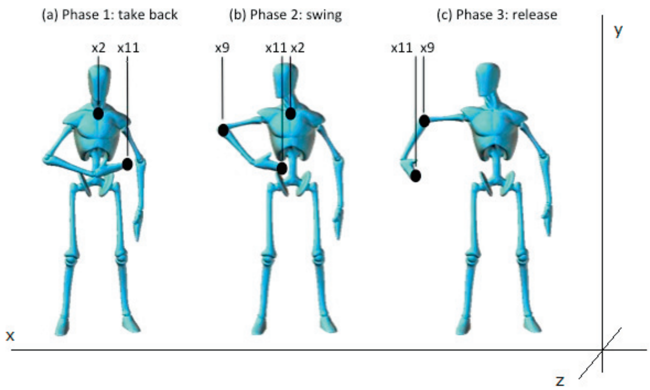

Fig. 2 Phases of the Throw

Hence this assessment is effective for spotting this error.

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

'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.

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 expressions (8)-(10) are used.

$$m1 = (z14-z18)/(x14-x18) \quad (8)$$
$$m2 = (z12-z16)/(x12-x16) \quad (9)$$
$$\text{if } (m2-m1)/(1+m1+m2) >= 0 \text{ then OK} \quad (10)$$

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

3.3. 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. Fig. 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.

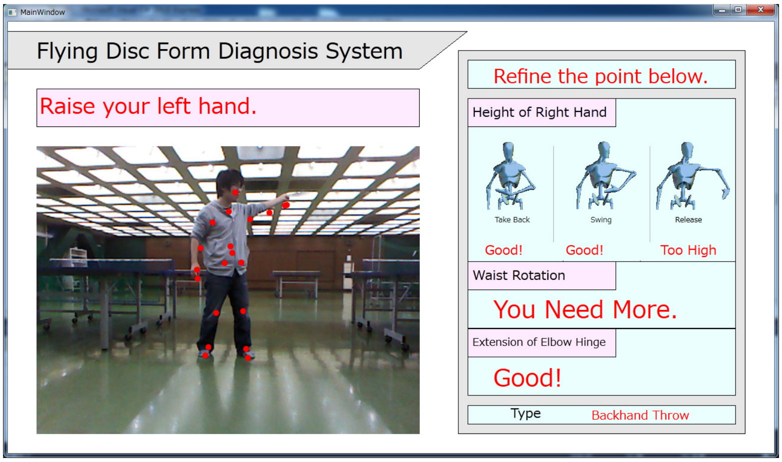

Fig. 3 Sample Screenshot of the proposing system

4. Experiment

4.1. Preparation

In order to verify the effectiveness of the proposing system described above, the authors performed a control experiment. Testees were 62 undergraduate students of Sophia University, and all of them were novice learners of flying disc throw. 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 Fig.3. The experiment was prepared to hang this fabric on the wall of a gymnastic hall of the university. Fig. 4 shows scenery of the experiment.

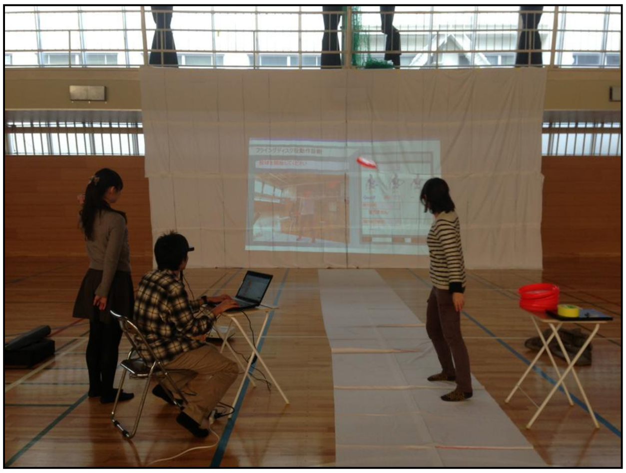

Fig. 4 Scenery of the experiment

The authors adopted two types of measurements. One was precision. It is measured how near a disc hits from the target mark drawn on the fabric. 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. The other one is testee's movement measured and assessed with use of the proposing system. As stated in section 3.2, it has 5 aspects of qualitative assessments. The authors converted these two types of results into grades. The total grade of each testee means summation of these two types of measurements.

4.2. Procedure

First, as a pre-test, all testees were examined the precision of the throws. They threw 10 flying discs to hit the target mark on the fabric. Total grades of all testees were measured and calculated. By this way, 62 testees were divided into 2 groups of 31 members, which were statistically insignificant. In the pre-test, the proposing system was used to measure testees' movements, but no feedback was given to testees.

Next, as a test, the target group members were given feedback in 5 times of throwing movement with use of the proposing system. As shown in Fig.4, a testee saw the visual feedback on the screen during throwing movement. On the other hand, the control group members had no feedback from the proposing system.

Finally, as a post-test, each testee was assessed 10 times in both precision and movement.

4.3. Result

Result of the experiment above showed that there was no statistical significance on the total grade written above (p=13%). Next, the authors divided two types of measures: precision and movement. There were two types of hypothesis: (a) the testees would improve their precision of throw with use of the proposing system, and (b) the testees would improve their movement of throw with use of the proposing system. However, from the t-test, there were no significances in both hypotheses of (a) and (b).

Moreover, the authors divided both the target and the control groups into 3 subgroups: upper, middle, and lower capability. When comparing between the lower target group and the lower control group, refinement of movement showed statistical significance (p=0.006%). For middle and upper groups, there were no significances (Table 2). On the other hand, refinement of precision showed no significance on upper, middle and lower groups (Table 3).

Table 2. Average value of movement

	target	control
upper	27.77273	25.93737
middle	24.07333	21.98889
Lower	26.45	12.21389

Table 3. Average value of precision

	target	control
upper	43.08671	42.46803
middle	38.4721	39.20177
Lower	29.56323	25.77821

5. Discussion

First, the authors are discussing the system functions and assessment criteria shown in the section 3.2 for more efficiency.

- Assessment of the "height of the right hand" has lower limit of point #1 (Spine), but this parameter may be too restrict. Point #0 (HipCenter) may be a more appropriate lower limit.
- 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.

These assessments are designed to determine what kind of feedback is effective for instructing rank beginners and novices limited specifically to throwing a flying disc. Below are points under consideration with regard to the functionality of the proposed system.

- Currently, the feedback given to the learner is text only. Adding audio and voice functionality will likely make the feedback more readily apparent to the learner.
- As mentioned in Section 2, there are two types of coordinates that can be obtained with Kinect: Point and Position. Currently, however, only Position coordinates have been utilized, which, although sufficient for assessing throwing form, would benefit from the inclusion of Point information. This would allow for the display of specific tracks/trails indicating proper height, arm movement, etc. within the images shown in Figure 3. This would likely improve the effect of the feedback.

Finally, the result of experiment shows significance in only one subgroup. The authors suppose that only 5 times of feedback with use of the proposing system is not enough to understand and adopt the feedback. So, further experiment is needed with more times of feedback.

6. 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 lower group to improve their movement. Future research will work to refine the current system vis-à-vis the points noted in Section 5, and retry to validate the efficiency of the proposing system with improved methods and sequence.

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