 http://doi.org/10.24867/JGED-2023-2-031

MTC: Visualization method of assessing physical movements with dribbling performance of basketball based in 3D Space

ABSTRACT

We present a basketball training visualization method – Motion Time Cylinder (MTC) designed to help novice players learn basketball techniques more easily. The basketball player can select their preferred movement to learn and visualize the body and joint movements in detail. Extensive visualization as a graphical assistant help supports the player in understanding 3D movements from the visual patterns. At the same time, players can understand the coordination and spatial relationship when playing the movement. The visualization principle is based on the mapping of body movement into the graphic of clock-based division locations. The movements can then be represented by the translation pattern between the frontal and transverse planes of cylinder spaces. As a result, the movement can be visualized by rendering the translation pattern base on the clock from a specific perspective, for example, an orthogonal view. This paper explains the visualization principles of the mapping and pattern as well as the graphical representation based on user perception.

KEY WORDS
Basketball training, visualization method, motion capture, body movements, graphical representation

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First received: 27.5.2022.
Revised: 3.11.2022.
Accepted: 9.11.2022.

Introduction

Basketball is one of the most widely practiced sports in the world, with over a billion participants worldwide. In a basketball game, not only the overall structure of an organization is demonstrated but also the tactical requirements, collaboration, timing, expertise, and level of physical fitness of the players on the court (Chiou, 2001). The majority of coaches believe that shooting is the most significant ability in basketball, but dribbling should be the first aspect of the game to be taught (Chi-Yang et al., 2006). Dribble is one of the fundamental offensive skills that encompasses a variety of performance forms (dribble with a change of direction, dribble hesitation, crossover dribble, inside and outside dribble, behind back dribble, dribble with pivoting and rotation, etc.) (Moselhy, 2020). Dribbling is defined as penetrating the ball while moving toward the basket and improving the passing angle. On the other hand, the dribbling technique is quite challenging to execute (Patel, Pandey & Bhownik, 2021). There have many detailed movements in the muscle and bones when the ball interacts with the ground and hands that require the player to perform high-level abilities of agility, motor control and manipulating the ball with fast-moving (Liu & Hodgins, 2018). It is crucial to have an effective dribble to be successful in any offensive strategy, especially if players are fast and defenders cannot stop them from shooting or cutting the ball off (Moselhy, 2020). Therefore, this skill requires players to maintain a higher level of physical balance and body coordination (Lu & Wei, 2021). It is necessary to visualize the movements and coordination of players who dribble from 3D to graphic visual spaces, which benefits novice players more visually by observing their body posture while dribbling and comprehending the complex body changes in basketball training. With the advancement of technology, numerous researchers have utilized motion capture systems to objectively analyze the basketball skill performance of players (Li, Rupčić & Knjaz, 2021). The term "Motion capture" refers to the process of recording motions and translating them into a digital representation (Pullen & Bregler, 2002; Müller & Röder, 2006). If we can visualize the digital model of motion capture, the characteristics can be discerned immediately. It is possible to use motion data visualization to aid in recognizing and analyzing human motion patterns (Hu et al., 2010). In this context, the main aim is to analyze and visually represent various basketball dribble variations in a visual graphic. Motion data can be visualized, which helps novice players understand dribble movement more quickly and clearly. (Hu et al., 2010). For example, the NBA carries out game motion tracking and data visualization and analysis by sportsVU, which converts data to video to provide advanced statistics for motion-tracking data, including the number of shootings, the average distance between defenders and the average speed (Yu & Chung, 2019).

Although previous work has explored sports data visualization to help basketball sports analysis and training, the research gap we emphasized is that most of the current research has focused on shooting, such as the success rate of the basketball free throw or the biomechanical analysis of the jump shot. Few researchers have examined the movements and coordination of basketball dribbling. Lots of studies focused on the detailed visualization of body movements and coordination. However, that makes the visualization principles and graphical representation complicated and not easy for non-research, for instance, teenage basketball novice players, to understand during training. It gives rise to the importance of an expressive graphical representation based on the design for user perception to visualize the changes in body coordination of a player during basketball dribbling in a visual space with extracted features. The design and definition of an effective visualization principle of dribble movement are needed.

In this paper, we present Motion Time Cylinder (MTC). This novel visual space visualization approach helps extract key dribble motion features and exhibits its variations in the player's body movement, which shows the different movement orientations. Furthermore, we have collected basketball dribble data from the Optical Motion Capture (OMC) system. These data allow us easy to understand the meaning of a basketball motion and measure the movements even though the dribble skills are complex.

To summarize, we have made the following contributions to this paper:

- We first use OMC to acquire motion data for various basketball dribbling movements based on human joint hierarchy.
- We propose the MTC system as a novel visualization approach and separate the orientation movements of specific body parts.
- Based on the complex and subtle movement of different body parts, convert the 3D motion patterns to MTC visual representation.
- Defining rules between patterns and motions to help novice players for better perception during basketball dribbling.

The structure of the paper is as follows: Section 2 discusses the related works on various kinematic analyses for basketball and sensing technologies in motion capture. Section 3 details the body coordination changes in 3D and the data collection system. Using the collected data, we show the method of MTC visualization on the ongoing basketball dribbling example in section 4. In the end, we conclude with a discussion of potential future work.

Related works

When players hold the ball in their hands and prepare for their next movements, they have three options in mind: dribbling, passing, and shooting (Arias-Estero, 2013). In the offensive action, players with proficient dribbling techniques are able to execute a variety of dribbling movements to break the defense of opponents, which paves the way for teammates to have more score opportunities (Arias-Estero, Argudo & Alonso, 2012; Arias-Estero, 2013). Conte et al. (2016) pointed out that effective dribbling skills play a vital role in a successful basketball game. Dribbling in the correct postures and angles can help reduce movement errors and increase the percentage of games won.

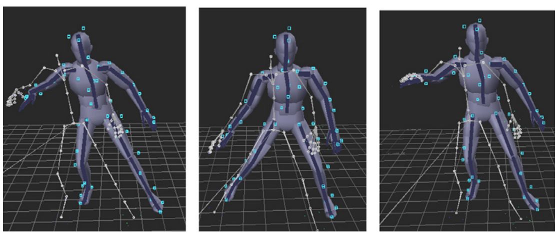
The impact of basketball skills on kinematics has been studied by researchers in the past. Iacob et al. (2014) discovered the correlation between the optimal arm and hand flexion during free-throw basketball. Their research revealed kinematic analysis regarding free throws under the basket and determined the angular motion velocity of each joint segment of the arm during the shot. This study significantly improved the shooting opportunities for players. Patel, Pandey & Bhownik (2021) discovered significant correlations between particular angular dynamics variables at the time of preparation for high dribble. Furthermore, they demonstrate a statistically significant relationship between high dribble performance and the right joints, such as the right hip, ankle, wrist, etc., during moment preparation and execution. However, to the best of the author's knowledge, no previous research has explored the visual changes of different basketball dribbling kinematics.

Humans have developed numerous techniques for representing motions in graphical and visual forms, allowing the audience to comprehend the nature of motion easily. Motion capture is practical and flexible in that data can be captured for any motion deemed essential to the research project. In addition, the data can be easily manipulated in terms of sample size and duration. Consequently, numerous research teams work with full-body motion capture and data visualization (Li, Bartram & Pasquier, 2016). Liu & Hodgins (2018) presented a method for achieving robust control of the basketball ball movement and coordinated arm motion from input motion capture data based on trajectory optimization and deep reinforcement learning. Their framework learns various static control graphs of basketball dribbling skills as reference motions to facilitate the basketball technique learning and interaction with simulated players for users. Furthermore, Starke et al. (2020) proposed a framework based on mixture-of-experts architecture to learn multiple and fast interactions between characters, basketball and environments from the motion capture database. However, these studies cannot be utilized to develop detailed controls for basketball skills. To properly execute the ideal dribbling movement, players must predict and accurately control the ball, hand touch and timing in advance. If coaches rely only on sample collecting and do not develop an awareness of strategy and analysis for players, they cannot perform such tasks effectively.

Balasubramanyam et al. (2020) proposed a Motion-Sphere, a trajectory-based visualization technique on the surface of a unit sphere, to represent human motion. The players are rendered as 3D avatars and visualized subtle motion as swing trajectories and twisting motion with color-coding. However, the work is concerned with the simpler actions compared to the high-speed movement of basketball and no visualization of the complex and high-speed motion data is shown as part of that work.

Visualizing body coordination changes in 3D

In this study, the OMC system is used to capture the variations in the player's body coordination during dribbling. As shown in Figure 1, these body coordination changes are translated into digital models and presented in 3D space.



» **Figure 1:** *3D full body skeleton model*

Motion tracking system

The OMC system is essential for human motion synthesis and analysis. In motion analysis, researchers use motion capture data to evaluate specific aspects of muscle and bone (Guerra-Filho, 2005). Specifically, the rubber balls are covered with reflective material and affixed to the specific joint location of players throughout the capture procedure. The cameras are calibrated to precisely receive light sources at a specific threshold and precisely capture the light source reflected from the rubber balls instead of other light sources, such as the light reflected off the skin (Estévez-García et al., 2015).

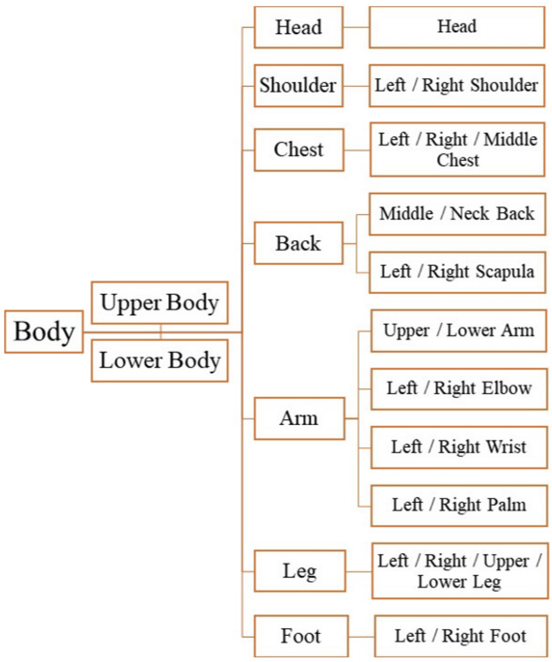
Researchers use 20 Optitrack cameras (Prime13) with a 90Hz sample rate to record the basketball dribbling motion into 3D data. Motive software is utilized to label the motion 3D coordinates, including the horizontal, vertical, and forward axes. Finally, researchers clean the data and export time series to analyze motion variables.

In this process, as shown in Figure 2, players wear tight-fitting black suits and are affixed with 44 reflective rubber balls as markers. These markers are placed on rigid parts of the body, including the head, shoulders, arms, back, pelvis, legs and feet.

» **Figure 2:** *The position of markers on rigid parts of the body*

Body hierarchy

As shown in Figure 3, the skeletal changes in human movement are hierarchical movements in which joint-bone segments have a parent-child relationship. This paper uses hierarchical modeling to visualize the posture and body coordination of basketball players. In the skeletal study of sports, the human body is typically considered as a skeleton tree formed of rigid bodies. Specifically, different hinges connect adjacent bones to each other to construct the skeleton tree. There is a parent-child relationship between the skeletons, with the child node skeletons rotating around the parent skeleton (Nie et al., 2021). It is possible to isolate “illustrable” portions of a skeletal motion capture sequence using a hierarchy. With this method, the basketball dribbling motion can be illustrated at the different specified joints.



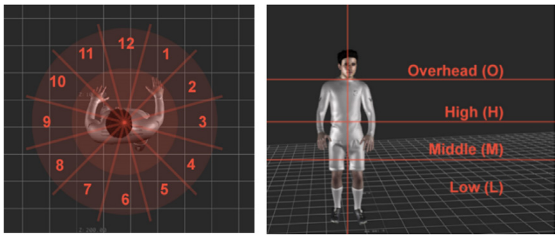
» **Figure 3:** *A skeleton tree of human motion capture data*

Visualization principles

The relationship of the direction, position pattern and the actual variations of the body coordination must be precisely defined and understand how the direction and position pattern represent the motions during basketball dribbling. Two planes are applied to relatively divide the surrounding movement space to define the rule between the pattern and the actual motion. All body parts are placed in a unit cylinder and can be divided into frontal and transverse planes around the players.

Motion Time Cylinder (MTC)

MTC is a novel visualization method based on user perception. It provides a visualization of the arm swing associated with basketball dribbling by clock motion and the joint position, as shown in Figure 4. Mapping the joint movements in a unit cylinder graphic, MTC represents variations in body direction and position when the players dribble the ball. MTC adopts different visual patterns to analyze body variations for players based on the frontal and transverse planes. The players' body direction and position variations are labeled on a cylinder of 12 equal parts. From the top-down view, the transverse plane based on the clock visualizes the variations of the players' arm swing translational. The frontal plane on the cylinder represents up and down variations of arm swing movement of players during dribbling. MTC enables players to perceive movement variations during basketball dribbling.



» **Figure 4:** *MTC visualization method*

Movement in MTC

The changes of direction (CODs) for body coordination and arm swing are key movements linked to decisive moments in basketball dribbling. Players need to perform a diverse range of CODs, from various angles; the ability to change dribble direction safely and quickly by arm swing is essential (Dos’Santos et al., 2018).

Transverse plane - position

The transverse plane of the body coordination changes for the player is divided into left-right and front-back movements and visualized as a clock graphic. Mapping time distribution on the unit circle help quantifies and visually analyze entire body motion and bone joint movements for players. Moreover, learning movements through clock distribution helps players easily understand arm swing and body movement changes during dribbling.

Frontal plane - direction

Height measurement is attached to the frontal plane of a unit cylinder to visually identify the joint movements up and down and longitudinal orientation variations. The body height and arm swing are divided into overhead, high, middle, and low zones from above the shoulder to below the knee. The frontal variation can be expressed as 4 zones to identify the direction of up and down movement of the arm swing in visual space. This method of representation has the advantage of being able to help the novice player to understand the changes of the body while dribbling in a simple way, even if it is a complex and high-speed basketball movement.

Visualizing the position and direction of swing motion

Due to the coordination and body hierarchy movement during the basketball dribbling, the inverse kinematics (IK) is presented based on the shoulders and elbows as the parent node stabilizes the wrists and hands as the child node. IK explains how to control the different joints of the arm to achieve the desired end-effector position change, which is critical to arm swing analysis, such as the child node moving around the parent node and providing motion direction to the parent node (Zhang & Hannaford, 2019). This paper focuses on describing the direction and position variations of the arm swing, which helps to provide basic instruction to novice players. So, in this example, we only describe hand position changes to help novice players understand dribbling skills more easily.

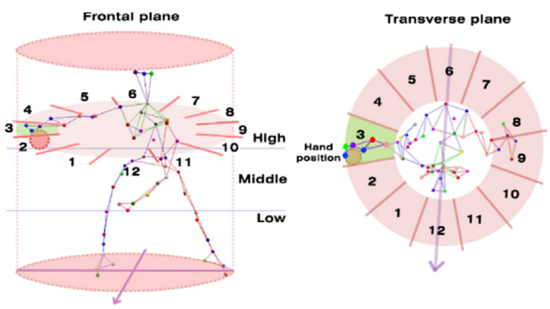
The proposed Motion Time Cylinder (MTC) is evaluated using professional basketball dribble data from the OMC system (involving position and direction changes with the hand). The low stationary dribble exercise, running dribble drill and defense are examples in this study.

Low stationary dribble exercise

The low stationary dribble is a cyclical task that mainly includes seven phases: right hand touches the ball (position); right hand pushes the ball (direction); bounce position; left hand receives the ball; left hand pushes the ball; bounce position; right hand receives the ball. A standard basketball dribble style is established. Participants are instructed to stay tall and look straight ahead for the duration of the dribble.

First step - right hand touches the ball

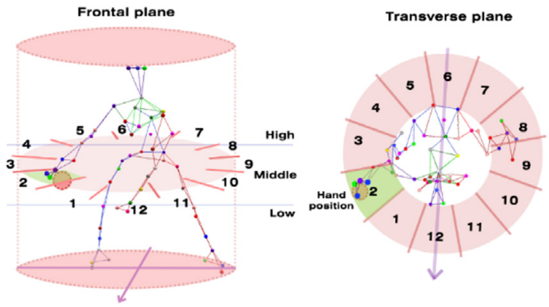
As shown in Figure 5, the player starts the first action of dribbling. From the transverse plane of the MTC system, the right fingertips grip the ball at 3 o'clock. From the frontal plane, the right hand position is at the high zone above the waist. Using the clock and body positioning allows novice players to quickly understand the hand position of the first action when dribbling the ball.



» **Figure 5:** *Right hand touches the ball*

Second step - right hand pushes the ball

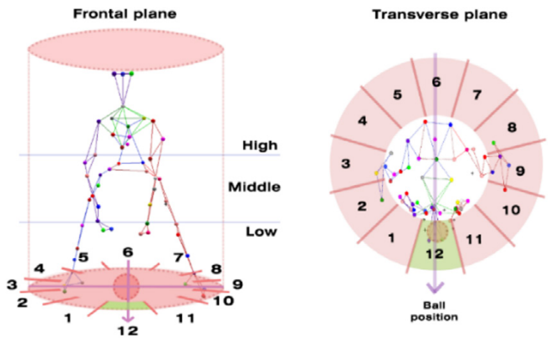
When the player pushes the ball to the floor while moving their hand and the elbow up and down, as shown in Figure 6, the right hand begins to push the ball counterclockwise in the direction from 3 o'clock to 2 o'clock. From the frontal plane, the player moves the hand from the waist in the high area to the knee position in the middle area. Novice players can understand the distance and direction changes of the hand and arm pushing downwards when dribbling the ball.



» **Figure 6:** *Right hand pushes the ball*

Third step - the ball bounce position

As shown in Figure 7, when the ball touches the floor, the hand temporarily loses contact with the ball at the lowest point during the dribbling cycle. Right and left hands naturally drop and maintain the same width as the shoulders. From the frontal plane, the hand from the knee position in the middle area to below the knee in the low area. At this position, the player needs to land the basketball at 12 o'clock.

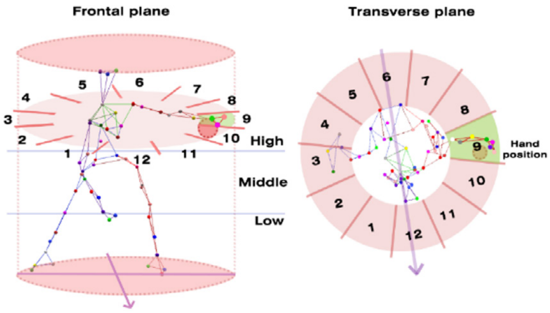


» **Figure 7:** *The ball bounce position*

Fourth step - left hand receives the ball

As shown in Figure 8, when the ball is transferred from the right-hand to the left-hand, at the same time, the player moves his left arm and hand upwards to receive the ball with fingertips at 9 o'clock and the hand at the highest point during the dribbling cycle.

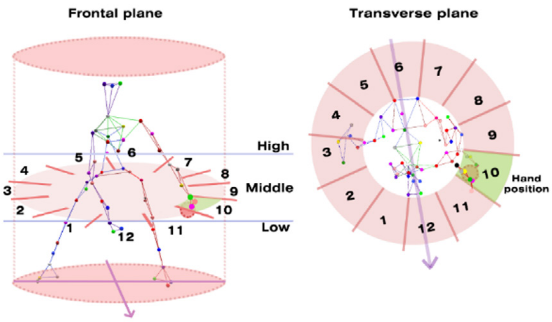
At this position, the left hand is in the high zone above the waist.



» **Figure 8:** *Left hand receives the ball*

Fifth step - left hand pushes the ball

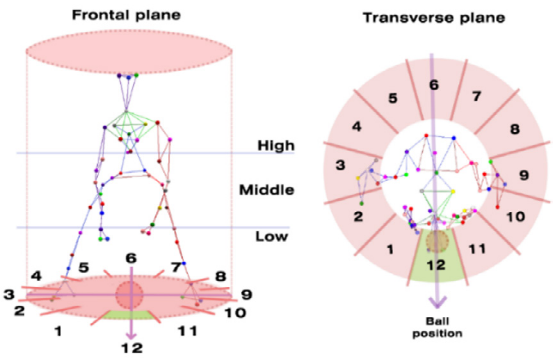
As shown in Figure 9, when the ball leaves the player's left hand, the left arm and fingertips begin to push the ball clockwise in the direction from 10 o'clock to 11 o'clock, and the left hand moves from the outer circle towards the inner circle. From the frontal plane, the player moves the left hand from the waist in the high area to the knee position in the middle area.



» **Figure 9:** *Left hand pushes the ball*

Sixth step - bounce position

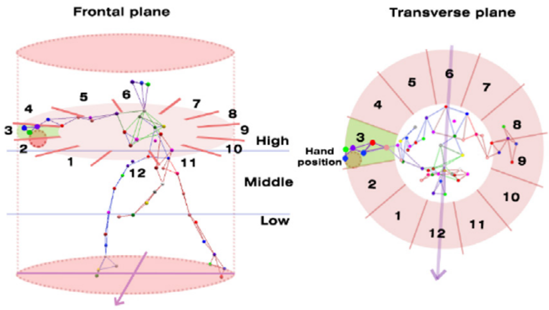
When the ball bounces to the floor from the left hand side, as shown in Figure 10, the right and left hands naturally drop and maintain the same width as the shoulders again and naturally downwards from the knee in the middle area towards the lower area under the knee.



» **Figure 10:** *Bounce position*

Seventh step - right hand receives the ball

The ball received in the right hand represents the end of a complete dribbling cyclical movement. As shown in Figure 11, the ball bounces clockwise off the floor towards the right hand. The right hand drives the wrist and arm clockwise up at the highest height of the dribbling cycle of 3 o'clock again. From the frontal plane, the right hand position at the high zone above the waist again.



» **Figure 11:** *Right hand receives the ball*

Running dribble drill

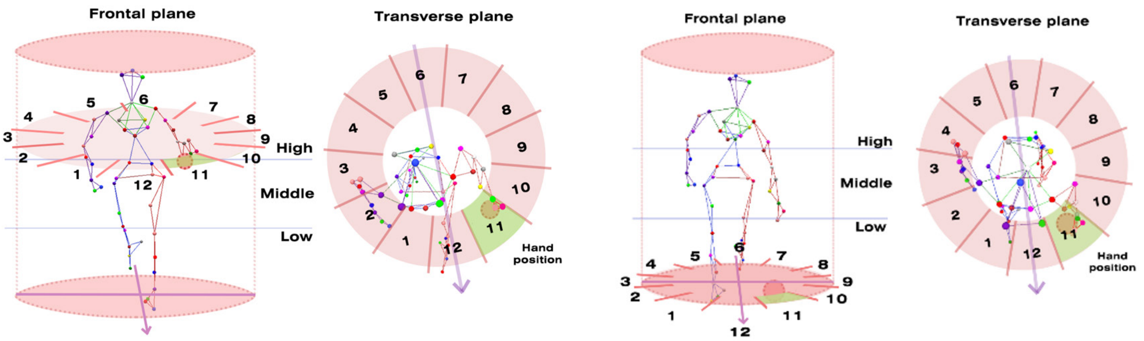
The previous movement has detailed introduced the MTC for individual low stationary dribble. The MTC is expanded in the two movements below to depict running dribble and defense, which enable players to quickly switch between a variety of basketball dribbling techniques.

As shown in Figure 12, when a player is running with dribbling on the court, right fingertips grip the ball at 11 o'clock from the transverse plane of the MTC system. From the frontal plane, the player moves the right hand from the waist in the high area to the knee position in the middle area.

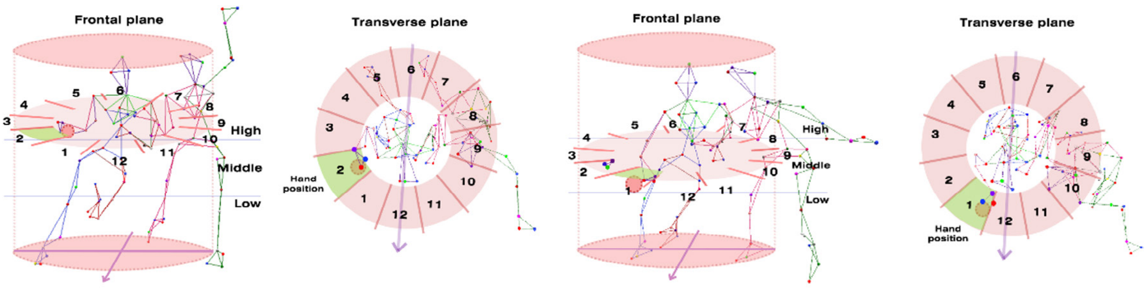
Dribble defense

When the player performs dribble defense drills. As shown in Figure 13, the MTC also can be utilized to help players standardize their arm and hand movements in a competitive atmosphere. From the transverse plane of the MTC, the right arm and fingertips begin to push the ball counterclockwise in the direction from 2 o'clock to 1 o'clock, and the player moves the right hand from the waist in the high area to the knee position in the middle area.

The MTC enables learning basketball to be simpler and makes it easier for novice players to understand basketball skills. Therefore, this method has a wide range of applications in comprehending the details of basketball skills, for example, actions and angles of pushing the ball, swing movements of the wrist, elbow and hand.



» **Figure 12:** *Right hand receives and pushes the ball*



» **Figure 13:** *Right hand receives and pushes the ball*

Evaluation

Participants and procedure

A total of 30 novice players ranging in age from 13- 20 years old attended in our study. We conducted the evaluation by comparing three different online learning methods (basketball coach video, 3D motion video, MTC visualization method). Players observed and learned 10 different dribble movements through three types of online basketball learning methods. At the end of this experiment, all participants used a five-Point Likert Scale (1, strongly disagree; 2, disagree; 3, neither agree nor disagree; 4, agree; 5, strongly agree) to answer a questionnaire survey that evaluate the effectiveness and satisfaction of MTC method in basketball dribbling learning process. The questions of Q1, Q2, Q5, Q8 were used to examined the satisfaction among participants and Q3, Q4, Q6, Q7 were used to identify the effectiveness of MTC. As shown in Table 1, the following is the questionnaire:

Table 1

The questionnaire to evaluate the MTC method

Satisfaction	Effectiveness
Q1: challenging dribbling techniques Q2: enjoyment on instruction methods Q5: visualization method for training Q8: recommendation of methods	Q3: comprehend the methods Q4: effective for dribble learning Q6: detailed dribble techniques Q7: learning dribble movements faster

Results

The purpose of this study is to determine the effectiveness and satisfaction of MTC visualization method in novices' basketball dribbling training. The scores of all participants for each question were summed to determine the combined average score for each question. Descriptive statistics were then calculated for the means and standard deviations to identify the effectiveness and satisfaction of MTC. The higher sample mean (M) score represents greater effectiveness of the MTC visualization method and the lower standard deviation (SD) score indicates higher consistency among all participants.

Table 2

The satisfaction of MTC visualization method

	Q1	Q2	Q5	Q8
M	4.60	4.30	4.20	4.30
SD	0.855	0.750	0.761	0.702

Note. M = sample mean; SD = standard deviation

As shown in Table 2, these four questions were used to test the level of satisfaction with the MTC method. The results showed that novice players were high satisfied with the method when the M scored higher than 4.00. The majority of basketball players believe dribbling is a difficult technique (M = 4.60, SD = 0.855). It is necessary to provide a visualisation method to support the novice player in comprehending dribbling techniques. Furthermore, after the epidemic, players realize the importance of online learning and they like learning skills without traditional coaches by online methods (M = 4.30, SD = 0.750). The results of questions 5 and 8 indicate that players enjoy training with MTC and will continue to use it with other players in the future (M = 4.20, SD = 0.761; M = 4.30, SD = 0.702).

Table 3

The effectiveness of MTC visualization method

	Q3	Q4	Q6	Q7
M	4.53	4.57	4.67	4.20
SD	0.681	0.728	0.547	0.805

Note. M = sample mean; SD = standard deviation

In aspects of MTC effectiveness, the M results of Table 3 scored higher than 4.00 show that MTC decomposes complex dribbling movements into easily understandable components for novice players and assists players in effectively training dribbling skills. With the MTC method, participants can learn the intricate dribbling movements in detail quickly (M = 4.67, SD = 0.547). Players are given the ability to comprehend the movements through the utilization of MTC, which is a productive method for training in basketball (M = 4.53, SD = 0.681; 4.57, SD = 0.728). Moreover, participants are able to learn dribbling skills more quickly with MTC compared to the other two methods, as indicated by Q7 (M = 4.20, SD = 0.805).

This study demonstrates that MTC visualization method provides participants with a high level of effectiveness and satisfaction when they learn basketball dribbling. The complexity and variety of basketball dribbling techniques present a significant obstacle for novice players. MTC- a simple and easy-to-understand training approach provides players with a great deal of assistance, allowing them to decompose complex movements into simple steps that make it easy for them to comprehend the essential aspects of key movements.

Discussion

Basketball is a flexible and fast sport. Since players differ in terms of skeletal length and flexibility, they all have different skeletal anatomy. In the previous sections, we present a visualization method- MTC, that enables analysis and illustration of basketball dribble movements from motion capture data and is effective for analyzing and visualizing the structural relationships between the joint-bone segments. Different joint and bone localizations are used to describe the motion position. We apply MTC to stationary dribble example of skeletal motion capture data. We successfully illustrate a complex cyclical dribble task using an easier and more intuitive method for basketball novice players.

Compared to complex detail visualization of body movements and coordination, such as precise angles and complex lines, the clock graphic-based can be used to describe the position and direction of the movement, which is the simplest and most understandable way for novice players to observe and train. So that novice players can more easily imitate the movements of professional players and not easily lose interest in training.

Through the basketball training visualization method - MTC, basketball novice players can clearly see the professional basketball player's hand movement during dibbling. With this visualization, novice players will have a clear overview of the overall basketball movements and give a correct evaluation of physical coordination.

Conclusion and future works

Creating a perception-based visualization method for basketball skills is a challenging task. This paper presents a motion visualization system that illustrates basketball training movements extracted from skeletal motion capture data and represents them in a visual space. Our approach analyzes the basketball dribble movements according to the range of time-varying positions and orientations of a body part and applies a number of non-photorealistic motions to illustrate the most important movements. Our method as a motion illustration enables a fast and effective motion analysis to help basketball novice players understand the basketball movements and the difference between two movements.

The current system is a basic functional foundation upon which to build in the future. Although our method at this stage is designed for basketball dribbling skills, we believe that it can be applied to any sports activities in analyzing user motion and help novice users understand other sports in the future. To further extend the proposed method, our goal includes that combine with AI for more precise action recognition and analysis. Motion analysis tools to better recognize behaviors and patterns in motions will be improved and extended to motion recognition by employing different classification methods. We will perform a thorough user evaluation of the MTC method, which will help to define the precise values for this method.

Acknowledgement

The authors would appreciate having this collaborative research with the research efforts partly supported by the Laboratory for Artificial Intelligence in Design under the InnoHK Research Clusters, Hong Kong Special Administrative Region Government.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

Arias-Estero, J. L. (2013) Opportunities for and success in dribbling, passing, receiving, and shooting in youth basketball. *International Journal of Sports Science & Coaching.* 8 (4), 703-711. Available from: doi: 10.1260/1747-9541.8.4.703

Arias-Estero, J. L., Argudo, F. M. & Alonso, J. I. (2012) Effect of ball mass on dribble, pass, and pass reception in 9–11-year-old boys' basketball. *Research Quarterly for Exercise and Sport*. 83 (3), 407-412. Available from: doi: 10.1080/02701367.2012.10599875

Balasubramanyam, A., Patil, A. K., Chakravarthi, B., Ryu, J. Y. & Chai, Y. H. (2020) Motion-sphere: Visual representation of the subtle motion of human joints. *Applied Sciences*. 10 (18), 6462. Available from: doi: 10.3390/app10186462

Chi-Yang, T., Wei-Hua, H., Yun-Kung, L. & Chin-Lin, H. (2006) The kinematic analysis of basketball three point shoot after high intensity program. In: *ISBS-Conference Proceedings Archive, 14-18 July, Salzburg, Austria.* Konstanz, International Society of Biomechanics in Sports.

Chiou, T. T. (2001) *Techniques and tactics of professional basketball-huang-kao elephant eeam.* Unpublished PhD thesis. National college of physical education and sports.

Conte, D., Favero, T. G., Niederhausen, M., Capranica, L. & Tessitore, A. (2016) Effect of different number of players and training regimes on physiological and technical demands of ball-drills in basketball. *Journal of Sports Sciences*. 34 (8), 780-786. Available from: doi: 10.1080/02640414.2015.1069384

Dos'Santos, T., Thomas, C., Comfort, P. & Jones, P. A. (2018) The effect of angle and velocity on change of direction biomechanics: An angle-velocity trade-off. *Sports Medicine*. 48 (10), 2235-2253. Available from: doi: 10.1007/s40279-018-0968-3

Estévez-García, R., Martín-Gutiérrez, J., Mendoza, S. M., Marante, J. R., Chinea-Martín, P., Soto-Martín, O. & Lodeiro-Santiago, M. (2015) Open Data Motion Capture: MOCAP-ULL database. *Procedia Computer Science*. 75, 316-326. Available from: doi: 10.1016/j.procs.2015.12.253

Guerra-Filho, G. (2005) Optical Motion Capture: Theory and implementation. *RITA*. 12 (2), 61-90.

Hu, Y., Wu, S., Xia, S., Fu, J. & Chen, W. (2010) Motion track: Visualizing variations of human motion data. In: *2010 IEEE Pacific Visualization Symposium, PacificVis 2010, 2-5 March 2010, Taipei, Taiwan.* Piscataway, IEEE. Available from: doi: 10.1109/PACIFICVIS.2010.5429596

Iacob, R., Budescu, E., Merticaru, E. & Oprişan, C. (2014) The kinematic model with three degrees of freedom associated to the direct throwing in basketball game. *Applied Mechanics and Materials.* 658, 495-500, Available from: doi: 10.4028/www.scientific.net/AMM.658.495

Li, F., Rupčić, T. & Knjaz, D. (2021) The effect of fatigue on kinematics and kinetics of basketball dribbling with changes of direction. *Kinesiology*. 53 (2), 296-308. Available from: doi: 10.26582/k.53.2.12

Li, W., Bartram, L. & Pasquier, P. (2016) Techniques and approaches in static visualization of motion capture data. In: *Proceedings of the 3rd International Symposium on Movement and Computing, MOCO '16, 5-6 July 2016, Thessaloniki, Greece.* New York, Association for Computing Machinery. Available from: doi: 10.1145/2948910.2948935

Liu, L. & Hodgins, J. (2018) Learning basketball dribbling skills using trajectory optimization and deep reinforcement learning. *ACM Transactions on Graphics (TOG)*. 37 (4), 1-14. Available from: doi: 10.1145/3197517.3201315

Lu, L. & Wei, W. (2021) Influences of core-strength training on the balanced capacity and partial blood biochemical indexes of university basketball players. *Frontiers in Educational Research.* 4 (7). Available from: doi: 10.25236/FER.2021.040714

Moselhy, S. H. (2020) Effect of speed, agility, and quickness (SAQ) training with and without ball on all types of dribble skill for junior female basketball players. *The International Scientific Journal of Physical Education and Sport Sciences.* 8 (1), 171-184. Available from: doi: 10.21608/isjpes.2020.21732.1001

Müller, M. & Röder, T. (2006) Motion templates for automatic classification and retrieval of motion capture data. In: *Proceedings of the 2006 ACM SIGGRAPH/Eurographics Symposium on Computer Animation, SCA 2006, 2-4 September 2006, Vienna, Austria.* New York, Association for Computing Machinery. Available from: doi: 10.2312/SCA/SCA06/137-146

Nie, S., Li, Y., Ma, B., Zhang, Y. & Song, J. (2021) The construction of basketball training system based on motion capture technology. *Journal of Healthcare Engineering.* 2021. Available from: doi: 10.1155/2021/2481686

Patel, S., Pandey, U. & Bhownik, S. (2021) Assessing the relationship of kinematics with dribbling performance of basketball at different phases. *Innovative Systems Design and Enggineering.* 3 (4), 6-12.

Pullen, K. & Bregler, C. (2002) Motion capture assisted animation: Texturing and synthesis. *ACM Transactions on Graphics.* 21 (3), 501-508. Available from: doi: 10.1145/566654.566608

Starke, S., Zhao, Y., Komura, T. & Zaman, K. (2020) Local motion phases for learning multi-contact character movements. *ACM Transactions on Graphics (TOG).* 39 (4), 54-1. Available from: doi: 10.1145/3386569.3392450

Yu, A. & Chung, S. S. (2019) Automatic identification and analysis of basketball plays: NBA on-ball screens. In: *2019 IEEE International Conference on Big Data, Cloud Computing, Data Science & Engineering, BCD, 29-31 May 2019, Honolulu, Hawaii.* Piscataway, IEEE. Available from: doi: 10.1109/BCD.2019.8885163

Zhang, D. & Hannaford, B. (2019) IKBT: Solving symbolic inverse kinematics with behavior tree. *Journal of Artificial Intelligence Research.* 65, 457-486. Available from: doi: 10.1613/jair.1.11592