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A Knowledge-Based Smart Trainer System for Transferring Knowledge From Coaches to Long Jump Students

Teerawat Kamnardsiri[1]*, *Pattaraporn Khuwuthyakorn*[2], *Sirinun Boripuntakul*[3] and *Worawit Janchai*[2]*

[1]Department of Digital Game, College of Arts, Media and Technology, Chiang Mai University, Chiang Mai, Thailand, [2]College of Arts, Media and Technology, Chiang Mai University, Chiang Mai, Thailand, [3]Department of Physical Therapy, Faculty of Associated Medical Sciences, Chiang Mai University, Chiang Mai, Thailand

Background: The constructive and specific feedback in guiding long jump athletes to improve their performance in each phase is part of the critical process for achieving desired long jump distance. However, to date, the potential approach for assisting a coach in capturing long jump movement and transferring their knowledge to long jump students is not well-established.

Objectives: To investigate the performance of long jump students and evaluate transferring knowledge from coaches to long jump students using a Knowledge-Based Smart Trainer (*KBST*) System.

Methods: Twenty-two participants (fifteen males, mean age = 15.33 ± 1.95 years; seven females, mean age = 14.57 ± 2.07 years) participated in the study. All participants were recruited from eleven sports schools in Thailand. Each participant was instructed to perform the long jump movement, including running, take-off, and landing, for three attempts (*Test 1*, *Test 2,* and *Test 3*). *Test 1* was the conventional approach (coaches provided the feedback based on their experience). *Test 2* and *Test 3* were the KBST system approach (coaches provided the feedback based on the results from KBST system). Two cameras were used to record the participant movement from the starting position to the landing position. The capture data were analyzed by KBST system program. The outcome measures were starting position, maximum velocity, maximum velocity position, and take-off angle. Repeated-Measures ANOVA was conducted to compare the long jump performance across the three trials. The statistical significance was set at p-value < 0.05.

Results: There was a statistically significant difference between *Test 1* and *Test 3* for long jump distance (mean difference = 0.292; Std. Error = 0.129; Sig. = 0.34). However, the mean of take-off angle was similar across the three trials (*Test 1* = 12.16°, *Test 2* = 12.71°, and *Test 3* = 12.95°, respectively).

Conclusion: The *KBST* system was effective in improving long jump students' performance and also transferring knowledge from the coach to long jump students.

Keywords: knowledge-based smart trainer, knowledge transfer, long jump, image processing, computer vision, smart system

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****Correspondence:***
Worawit Janchai
worawit.j@cmu.ac.th

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INTRODUCTION

The long jump is one part of track and field sports in school athletic events. The long jump was contained in the first Olympics in ancient Greece, circa 708 BC. Long jump biomechanics is comprised of four phases, including the approach-run phase, take-off phase, flight phase, and landing phase (Linthorne, 2008; Kamnardsiri et al., 2015a). The desired long jump distance requires a proper strategic movement in each phase, following through with the judge's criteria for evaluation (Santos and Shannon, 1989; Alexander, 1990; Hay, 1993). Specifically, the optimal action in each phase has an effect on the flight distance; thus, the athlete's performance in each phase has to be concerned.

Commonly, one of the key factors that influence the long jumpers' performance is an experienced expert in the long jump biomechanics who is able to provide suggestions and feedback to the long jumper. However, the availability of qualified coaches in this field has still been quite limited recently. Almost all of the long jump coaches only passed the basic level (Level I-II course) of the IAAF Coaches Education and Certification System (Worldathletics, 2005). In this circumstance, a Human Visual System (HVS) error would be inevitable due to constructive feedback that is specific for athletes to upgrade their skills relying more on their coaches to be proficiently skilled when providing advice (Level III to Level V). Consequently, there might be some negative effects on the long jumper's performance, whereas incorrect suggestions are unintentionally provided by the coaches. To overcome this shortcoming, coaches need some accessibility approaches to assist them in capturing long jump movement and then giving appropriate feedback to the long jumper (Kamnardsiri et al., 2019a).

Motion capture systems and timing gates were employed as gold standard approaches for measuring speed and take-off angle (Graham-Smith and Lees, 2005; van der Kruk and Reijne, 2018). Nevertheless, these approaches are costly and time-consuming in the configuration system, which might be a practical barrier in that working field. Besides, some systems have a cost limitation for procurement.

Computer technology has been developed in supporting coaches for measuring and analyzing data from the athlete, for example, video analysis (Bryan, 2004), game analysis (O'Donoghue, 2013; O'Donoghue, 2015), sports tracking (Gade and Moeslund, 2018), human motion tracking (Krzeszowski et al., 2017; Shah et al., 2017), and especially computer vision techniques that are an essential role in the development of tools for analyzing the movement, recreation and sports activities, and athletic skills of participants (Leo et al., 2017). In the previous works, several researchers studied computer sciences in sports; for instance, Theodorou et al. (2017) investigated the relative influence of step length and step frequency on step velocity during the approach-run of high-level long jumpers using a high-speed video camera. Scott et al. (1997) studied the association between non-long jumpers and experienced long jumpers in footfall placement between trials using the manually panned system capturing the video with a camera record. Hsu et al. (2006) developed automatic motion detection during a standing long jump. Video sequence images were segmented by using the background subtraction technique. The features of all frames were extracted by the Pose Estimation and the Hue-Saturation-Value (HSV) space. They employed the genetic algorithm-based (GA-based) approach to learn the joints of the person. The results showed that the joints of the person could generate the required movements for studying the performance. Dubois et al. (2012) used an image processing technique for measuring the freestyle swimming biomechanics. Video footage was analyzed using an image processing technique. Autodetection for arms and legs data was performed, whereas data were analyzed for improving the movement of each athlete. Kamnardsiri et al. (2019a) investigated the requirement of the Knowledge-Based System for training long jump from coaches (sports schools) and designed the system from the long jump experts (passed the Level III course from IAAF). The results indicated that the students acquired "*Correct after jump from only coach suggestion*" as 100% and also "*Need the expert system*" is 100% to help coaches improve the capabilities of the long jumper. The coaches employed the video camera to capture long jump movement at 71.43%. Therefore, the Knowledge-Based Smart Trainer (*KBST*) system is one of the considerations in systems procedure for transferring the coach's knowledge to the long jump athlete. This study aims to evaluate the performance of the long jump students and transferring of knowledge from the coach to the long jump students using the *KBST* system.

The present study aims to investigate the performance of long jump students with and without the *KBST* system. We hypothesized that after applying the *KBST* approach, the performance of long jump students would demonstrate a significant improvement. This information would address an effective and practical approach for transferring experts' knowledge to coaches and long jump students.

KNOWLEDGE-BASED SMART TRAINER SYSTEM

According to the Knowledge-Based System for long jump training, the approach-run phase was designed by long jump experts and developed by using the Matlab R2015a in combination with the Computer Vision System Toolbox and the Image Processing Toolbox. The system design is comprised of the 1) design Knowledge-Based System framework (Kamnardsiri et al., 2015a; Kamnardsiri et al., 2015b) and 2) knowledge-based condition for training the long jump (Kamnardsiri et al., 2019a). Moreover, the Knowledge-Based System for Training Long Jump Athletes was developed and then validated for knowledge transferring (Kamnardsiri et al., 2018; Kamnardsiri et al., 2019b).

In this study, we applied the system design and development of Kamnardsiri et al. (2019a) and then modified the suggestion phase of both the approach-run and take-off phases. Also, we added the take-off phase into the system and then redefined the name as the Knowledge-Based Smart Trainer (*KBST*) system, which is comprised of four sections (**Figure 1**).

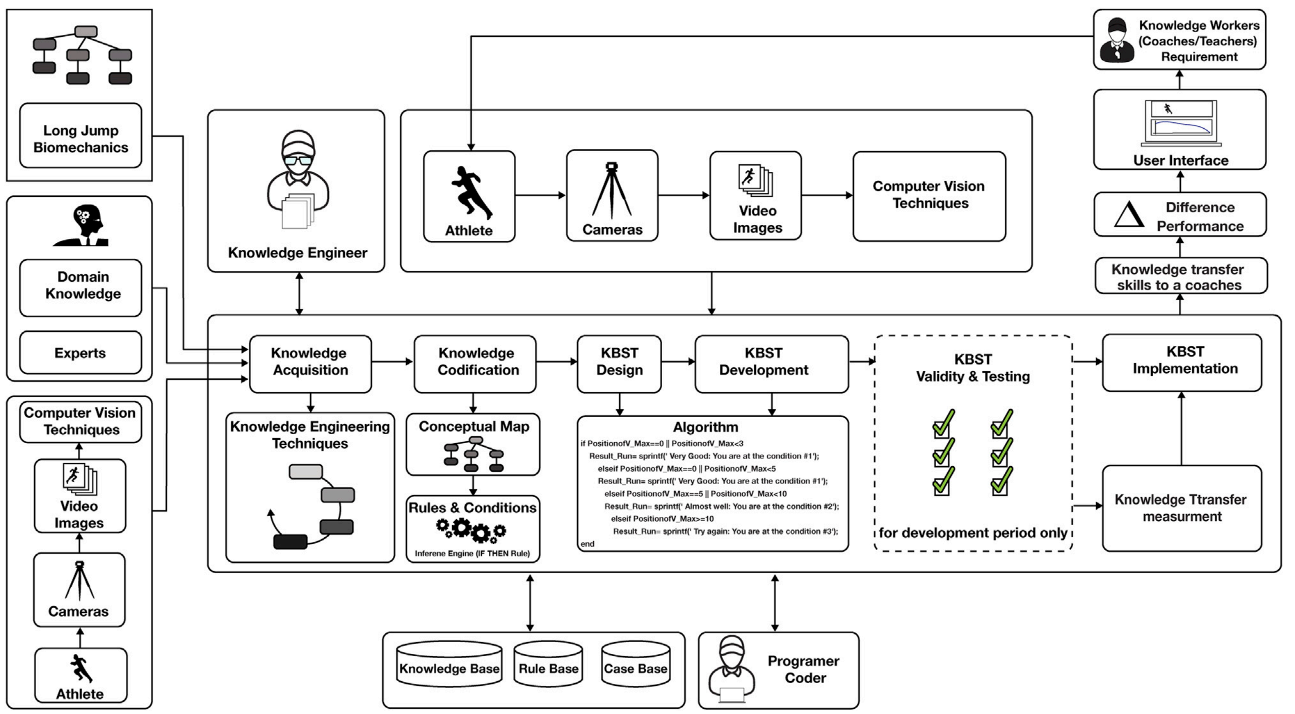

FIGURE 1 | The Knowledge-Based Smart Trainer system framework.

Domain Knowledge

The domain knowledge involves a combination of knowledge from professionals' experiences (long jump experts) at long jump biomechanics. All experts need to pass at least the Level III course of the IAAF (Worldathletics, 2005). Moreover, computer vision techniques are considered for collecting video data.

KBST Process

To develop the system, the *KBST* system employed the process of Knowledge-Based System (KBS) development process (Akerkar and Sajja, 2009; Sajja and Akerkar, 2010). The main key to this process is a Knowledge Engineer (KE) (Studer et al., 1998; Laudon, 2003; Laudon and Laudon, 2011). KBS applies technology into the organization that is managed with the organization's assets, for instance, expert systems, rule-based systems, case-based systems, and database management systems (Becerra-Fernandez and Sabherwal, 2014). The *KBST* process consists of the following four parts:

- Experts' knowledge is captured using a knowledge acquisition process with knowledge engineering techniques and codified into the conceptual map, rules, and conditions (inference engine).
- Design and development of the *KBST* system are performed to convert experts' knowledge into the algorithm to produce the knowledge engine.
- Validity and testing are operated only in the earlier implementation development period of the *KBST* system. The importance of this process is the programmer or coder.
- The indirect knowledge transfer process is measured from the results of the athlete to check the knowledge transfer from the *KBST* system to coaches after testing.

Computer Vision

Computer vision techniques (Weinland et al., 2011) are used for capturing input data from standard video cameras, and then the data is loaded into the computer. Besides, all captured data are processed by computer vision techniques to be compared with the inference engine.

Knowledge Workers

Knowledge workers in this study make the knowledge suggestion and the results are computed with Algorithm 1 and Algorithm 2 of the *KBST* system. The knowledge is transferred to coaches (knowledge workers). Therefore, the *KBST* system is able to assist coaches in monitoring and planning programs to improve the individual skills of the long jump student.

MATERIALS AND METHODS

Participants

Twenty-two long jump students aged between 15 and 20 years were recruited from six sports schools in Thailand: 1) Lampang province (five students), 2) Suphanburi province (three students), 3) Nakhon Sawan province (two students), 4) Khonkaen province (four students), 5) Trang province (four students), and 6) Nakhon Si Thammarat province (four students) were included in participation event.

Algorithm 1 Approach-run suggestion algorithm.

Input: *V_Max*, *PositionofV_Max*Output: Result_Run, Result_suggesstion

Begin
if *V_Max* < 5 then
Result_Run = **"*Sorry your maximum velocity (*V_{max}*): V_MAX* m.s^{-1}. that is not suitable for long jump. The maximum speed should be more than 5 m.s^{-1}."**
Result_suggesstion = "Suggestion:

You should try again with more speed-up.
You should practise your speed performance."
elseif *PositionofV_Max* == 0 || ***PositionofV_Max*** <=5 then
Result_Run = **"*Very Good: You are at the Rule* #1**
Maximum velocity (*V_{max}*): *V_MAX* m.s^{-1}.
Maximum velocity position (*$V_{max\ position}$*): *PositionofV_Max* m."
Result_suggesstion = "Suggestion:
This is good running but you have to control the velocity to take-off.
Your maximum velocity is this position, so you should control the speed for taking-off.
Please do not reduce your speed and keep this speed level or increase your speed-up before the next jump.
You should move the starting-point equivalent lose space to the take-off board from the last starting-position but the speed is still the same with each running attempt."
else if *PositionofV_Max* > 5 || ***PositionofV_Max*** <= 10 then
Result_Run = **"*Almost well: You are at the Rule #2***
***Maximum velocity (*V_{max}*): V_MAX* m.s^{-1}.**
Maximum velocity position (*$V_{max\ position}$*): PositionofV_Max m."
Result_suggesstion = "Suggestion:
Before reaching to the take-off board, you should have two check makes.
You have to shift in from start point to take-off board.
Good, but you should keep this maximum speed to take-off board. The controlled maximum speed should be less than 5 meters from the take-off board.
In the real competition situation, you will adjust the new marker using around 14-17 soles (2 strides of running) to come take-off board.
You should move the starting-point equivalent lose space to the take-off board from the last starting-position but the speed is still the same with each running attempt.
Do not take more long stride or short stride of a leg before take-off"
elseif *PositionofV_Max* > 10
Result_Run = **"*Try again: You are at the Rule* #3**
Maximum velocity (*V_{max}*): *V_MAX* m.s^{-1}.
Maximum velocity position (*$_{Vmax\ position}$*): *PositionofV_Max* m."
Result_suggesstion = "Suggestion:
Number of stride ratio of all distance from the start point to the first check mark should be more than the last period before reaching to the take-off board.
You should slightly increase to the take-off board. It is unable to use this speed for taking-off. You should practise the approach-run again.
You may start with over fast running that is why Vmax appears in this period. It affects the athlete who is unable to preserve and control the speed for taking-off.
You should start with around 10-20 m. with long stride from the take-off board, then each stride adjusts your speed at 5-10 m. and the maximum speed should be around 0-5 m. from the Take-off board.
You should gradually increase speed from starting position to check mark point, then perform the fastest speed around 0-5 m from take-off board.
Increasing speed, the jumper gradually straightens up and run to become more upright and go along with a smooth stride pattern.
Rhythm in each approach increases your pace at the same rate and takes care to keep the degree of muscle contraction uniform.
One checkmark at a distance which is the midpoint of the run is usually sufficient."
end if
end

Participants took part in the evaluation of performance improvement from the system. In addition, participants were recruited based on the following inclusion criteria: those who were Thai nationals, in healthy condition, identified as long jump athletes between the ages of 15 and 20 years, able to run a fast 25–30 m dash and jump into the sandpit, and able to comprehend instructions and willing to participate. Moreover, the exclusion criteria were the presence of physical conditions such as a musculoskeletal injury that preclude participants from completing the testing protocol, taking alcohol 6 h before testing, or using drug regimens that had a negative effect on the running performance. All methods have been followed in agreement with the relevant guidelines and with the principles outlined in the Declaration of Helsinki and were approved by the Chiang Mai University, Research Ethics Committee, Chiang Mai, Thailand (*number CMUREC 61/044*). All of the participants provided their informed consent from their parents prior to participation. The acceptable participants were informed of the study's purposes before signing the informed consent.

Protocol

Participants wore a black sport long-sleeved shirt and black sport jogger pants. Each participant performed the long jump movement (running, take-off, and landing) for three tests (*Test 1*, *Test 2*, and *Test 3*). Prior to testing, all participants were engaged in warm-up protocol, including stretching, dynamic exercises, and jogging. After that, they performed the long jump under the supervision of the coach until achieving their regular maximal performance (*Test 1*). Therefore, *Test 1* was the traditional approach or baseline trial in which participants obtained usual coach feedback without *KBST* results (e.g., "*Try Again,*" "*Almost well*" or "*Good*"). Following the

Algorithm 2 Take-off suggestion algorithm.

Input: *Take_off_angle*
Output: Result_Jump, **Result_suggesstion**
Begin
if *Take_off_angle* <= 5 then
Result_Jump = **"Sorry you did not take-off! Your take-off angle is: *Take_off_angle* that is not suitable for the take-off phase."**
Result_suggesstion = "Suggestion:
The take-off angle should be more than 5.
You should try again with more take-off angle.
You should practice your take-off performance."
elseif *Take_off_angle* >= 18 then
Result_Jump = **"Very good: Your take-off angle is: *Take_off_angle*."**
Result_suggesstion = "Suggestion:
The swinging leg movement must begin from the hip that is shifted forwards and upwards.
The forward drive must be braced, so that the driving force can be transmitted to the body.
During the swing, the leg remains well flexed at the knee joint, the thigh should be reached at the horizontal at the end of the take-off action.
A forward inclination of the line of force can be increased through an effective swing, hence creating favourable conditions for the backward rotation.
The transference of movement is from swinging the leg and the arms to the trunk, the arms moved up but were quickly braced. The elbows are slightly turned out, hence the shoulders can be raised more easily and balanced that is more easy to be maintained."
elseif *Take_off_angle* >= 45 then
Result_Jump = **"Fair: Your take-off angle is: *Take_off_angle*."**
Result_suggesstion = "Suggestion:
You should reduce the take-off angle.
Take-off angle could be around 18-22 degree as an appropriation for long jump.
When starting to jump the take-off leg side could be straight.
You must be careful to maintain the spring in your muscles.
You should increase your horizontal velocity of running before take-off.
You do not wait until the foot has touched the ground, but place the leg, with a quick grabbing movement, back and down."
else
Result_Jump = **"Fair: Your take-off angle is: *Take_off_angle*."**
Result_suggesstion = "Suggestion:
The swinging leg movement must begin from the hip that is shifted forwards and upwards. Your horizontal velocity must be transformed into a vertical velocity momentum, which is directed forward and upward, take-off foot should be set somewhat further forward.
The body during take-off could be straight and a bit lean toward.
Practicing neural correlation and muscle movement is very important; athletes could practice this skilled.
You must be careful to maintain the spring in your muscles.
You must assume a more upright position, since the forward lean used in sprints would prevent a good take-off lift.
You should take a lower approach of your CG in the penultimate stride and lift all parts of your body during take-off.
During the last strides, knees are picked up high in the front in preparation for the energetic forward drive of the free leg.
The last stride must, in the first place, bring the flight phase rapidly to an end, so the curve of the CG of the jumper has no descending branch but moves only upwards after lowering the penultimate stride.
Synchronize to relax your arm movements."
end if
end

protocol for testing of the *KBST* system, participants performed long jump for two attempts (*Test 2* and *Test 3*, respectively) with sufficient rest between each test. The coach acquired the results from the *KBST* and provided the participants with the suggestion after *Test 1* and *Test 2*. The starting position ($Start_{Position}$), maximum velocity (V_{max}), maximum velocity position ($V_{maxPosition}$), and take-off angle (θ) were assessed from a total of all long jumps on the synthetic running track, flat and dry. The protocol for testing of the *KBST* system consisted of four located markers that were *M1* at the starting point of the long jump sand pit, *M2* at the take-off position, *M3* at 5 m far from the take-off position, and *M4* at 10 m far from the take-off position. The first camera was posited about 10 m far from the take-off position (*M2*). The second camera was posited about 25 m far from the marker (*M4*). Both cameras were fixed on the three-way head tripod with a height about 1.5 m from the floor (**Figure 2**).

Materials for motion capture in this study are comprised of the following: 1) Camera 1, standard video camera (*Nikon 1 J1, Japan*) with 10–30 mm lens; 2) Camera 2, standard video camera (*Casio ZR-55, Japan*) with 25 mm lens; 3) two tripods and three-way heads; 4) floor markers *M1*, *M2*, *M3*, and *M4*; 5) black sport long-sleeved shirt; 6) black sport jogger pants.

Procedure

Evaluation of performance improvement using the *KBST* was conducted by comparing *Test 1*, *Test 2*, and *Test 3*. The phase consists of four substeps as follows: 1) capturing the long jump *Test 1*, giving suggestion from *KBST*, and correcting jump; 2) capturing the long jump *Test 2*, giving suggestion, from *KBST* and correcting jump; 3) capturing the long jump *Test 3* and giving suggestion from *KBST*; 4) analyzing the captured data.

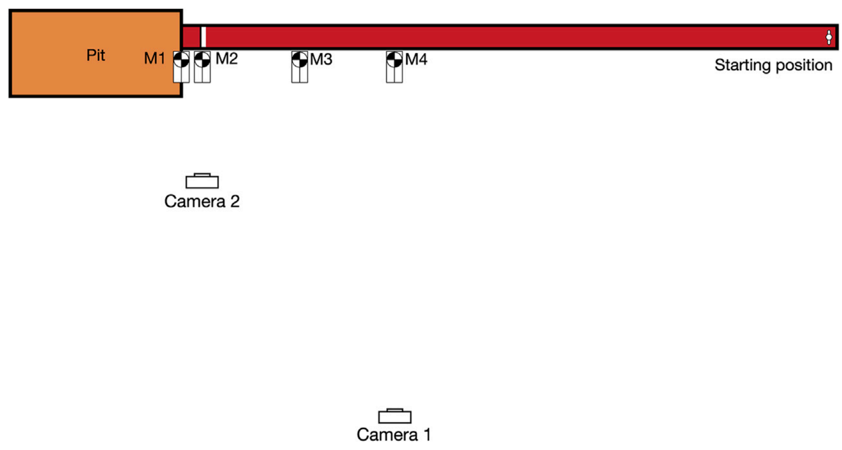

FIGURE 2 | The protocol of the Knowledge-Based Smart Trainer system for testing.

Data Acquisition and Analysis

The approach-run phase standard video camera (Camera 1) was set at the original size of 1,280 × 720 pixels and 60 Hz for capturing data. The camera was employed to capture the participant running from the starting position to the take-off position. The take-off and landing phase standard video camera (Camera 2) was set at the size of 640 × 480 pixels and 120 Hz for capturing data. All captured data were downloaded and analyzed using the *KBST* system that was utilized for calculating the starting position ($Start_{Position}$), maximum velocity (V_{max}), maximum velocity position ($V_{maxPosition}$), and take-off angle (θ). The task of collecting data was organized three times (*Test 1*, *Test 2*, and *Test 3*).

Statistical Analyses

All data were analyzed using IBM SPSS Statistics 21 for Windows (SPSS Inc., Chicago, IL, United States) with a statistically significant difference of $p < 0.05$. The descriptive statistics (means, SD, and variance) were employed for calculating demographic profiles and long jump variables of the participants. The One-Way Repeated-Measures ANOVA was employed for analyzing the significantly significant differences across the three tests.

Data Collection Location

This study was conducted at six sports schools in Thailand in Lampang province, Suphanburi province, Nakhon Sawan province, Khonkaen province, Trang province, and Nakhon Si Thammarat province. The time for testing was around from 9:00 am to 11:00 am.

RESULTS

Demographics Profile of Participants

Twenty-two participants (15 males: age 15.33 (1.95) years, weight 62.93 (8.97) kg, height 174.60 (9.09) cm, BMI 20.54 (1.27) kg m^{-2}; 7 females: age 14.57 (2.07) years, weight 50.57 (4.64) kg, height 161.14 (4.52) cm, BMI 19.45 (1.22) kg m^{-2}) successfully completed three tests without any incident. The participants' demographic characteristics indicated that the participants in this study are long jump students as a relatively healthy group (**Table 1**).

Long Jump Performance of Participants

The long jump variables contained the starting position ($Start_{Position}$), maximum velocity (V_{max}), and maximum velocity position ($V_{maxPosition}$), take-off angle (θ), and long jump distance. These variables were calculated by the *KBST* system. The variable of long jump distance was only evaluated with a tape measure. Twenty-two long jump students performed three long jumping tests. The results indicated that the majority of the long jump students improved the mean of long jump distance as *Test 1* = 4.88 m, *Test 2* = 5.09 m, and *Test 3* = 5.17 m, respectively. There was the significant difference at the 0.05 level between *Test 1* and *Test 3* (mean difference = 0.292*; Std. error = 0.129; Sig. = 0.34). However, the mean of take-off angle does not indicate a difference as *Test 1* = 12.16°, *Test 2* = 12.71°, and *Test 3* = 12.95°, thus illustrating that it has improved a little bit, whereas the mean of velocity was slightly declined from *Test 1* = 7.30 m s^{-1} as *Test 2* = 6.93 m s^{-1} and *Test 3* = 6.86 m s^{-1} (**Figure 3** and **Table 2**).

The Percentage of Suggestion From *KBST* System

For the percentage of the suggestion, the coach, acquiring the long jump biomechanics information of individual participant after

TABLE 1 | The participants' demographic characteristics.

Variable	Male (n = 15)	Female (n = 7)	All (N = 22)
Age (years)	15.33 ± 1.95	14.57 ± 2.07	15.09 ± 1.97
Weight (kg)	62.93 ± 8.97	50.57 ± 4.64	59.00 ± 9.72
Height (cm)	174.60 ± 9.09	161.14 ± 4.52	170.31 ± 10.09
BMI (kg m^{-2})	20.54 ± 1.27	19.45 ± 1.22	20.19 ± 1.33

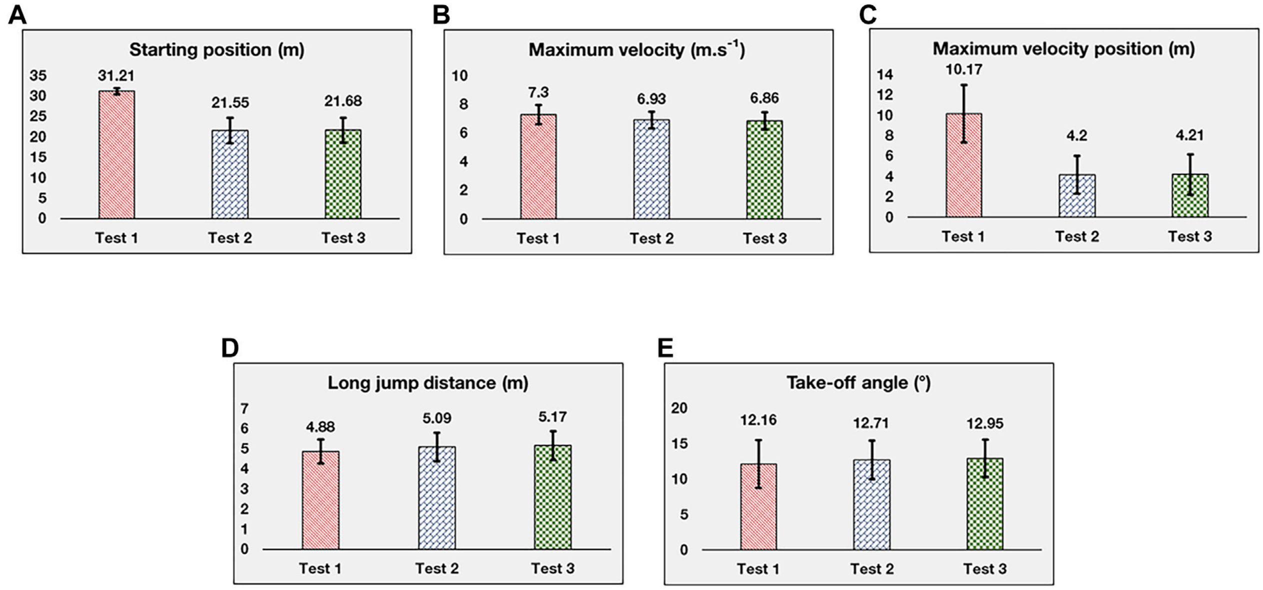

FIGURE 3 | Three long jump performance tests: **(A)** starting position, **(B)** maximum velocity, **(C)** maximum velocity position, **(D)** long jump distance, and **(E)** take-off angle.

the *KBST* system, had the data calculated from the video sequences of two cameras. The results demonstrated that the majority of the "*Try again*" suggestion was approximately 59% and the "*Almost well*" suggestion was about 36% in *Test 1*. After the KBST system provided the long jump suggestion contents to each teacher, participants practiced individually with some coaching in the long jump biomechanics. The results of the "*Very good*" suggestion in *Test 2* and *Test 3* were about 82 and 73%, respectively. However, in the take-off phase, the results revealed that *Test 1*, *Test 2*, and *Test 3* had the "*Fair*" suggestion from the system at about 95%. Nevertheless, the "*Very good*" suggestion was significantly 1% less in approximation (**Table 3**).

Evaluation of Long Jump Students' Performance Improvement

The performance of long jump students was evaluated using the statistical analysis as One-Way Repeated-Measures ANOVA for calculating the significantly significant difference among tests. The results presented that the mean difference between *Test 1* and *Test 3* was 0.292 at a significant level ($p < 0.05$). Nonetheless, the mean difference between *Test 1* and *Test 2* showed no difference (**Table 4**).

DISCUSSION

This study demonstrated that the *KBST* system can be used as a video-based assessment tool for transferring knowledge from coaching to the long jump students. Two standard cameras were employed in this study for capturing long jump data from each student and then Algorithm 1 and Algorithm 2 calculated the long jump performance of the students. Furthermore, the *KBST* can also provide suggestions from experts' knowledge that can be transferred to the coach and then each long jump student obtains that knowledge to enhance their performance. Finally, long jump students can be retrained and retested from the new suggestion of the coach.

This study found that the relationships between take-off distance, take-off angle, and run-up speed were in agreement

TABLE 2 | Descriptive statistics of the long jump tests (*N = 22*).

Variable	Minimum	Maximum	Mean	SD	Variance
Starting point (m)					
Test 1	30.00	32.93	31.21	0.73	0.53
Test 2	15.51	28.81	21.55	3.10	9.63
Test 3	15.63	28.95	21.68	3.06	9.37
Maximum velocity (m s^{-1})					
Test 1	6.24	9.05	7.30	0.66	0.43
Test 2	5.96	7.92	6.93	0.58	0.34
Test 3	5.67	7.90	6.86	0.60	0.37
Maximum velocity position (m)					
Test 1	2.48	14.02	10.17	2.80	7.86
Test 2	1.47	9.11	4.20	1.85	3.43
Test 3	1.53	8.82	4.21	1.99	3.95
Take-off angle (°)					
Test 1	6.90	18.19	12.16	3.40	11.54
Test 2	8.38	19.43	12.71	2.71	7.33
Test 3	8.91	18.60	12.95	2.64	6.96
Long jump distance (m) with the tape measure					
Test 1	4.01	6.01	4.88	0.60	0.36
Test 2	3.97	6.58	5.09	0.71	0.51
Test 3	3.83	6.32	5.17	0.71	0.51

TABLE 3 | Percentage of the suggestion by the *KBST* system (n = 22).

Long jump phase	*Test 1* (%)	*Test 2* (%)	*Test 3* (%)
Approach-run			
Very good	1 (4.50)	18 (81.80)	16 (72.70)
Almost well	8 (36.40)	4 (18.20)	6 (27.30)
Try again	13 (59.10)	0 (0.00)	0 (0.00)
Take-off			
Very good	1 (4.50)	2 (9.10)	1 (4.50)
Fair	21 (95.50)	20 (90.90)	21 (95.50)

with the previous studies (Alexander, 1990; Hay, 1993; Seyfarth et al., 2000; Linthorne et al., 2005; Bridgett and Linthorne, 2006). Unfortunately, the take-off angle in this study was lower than the optimum take-off angle for long jump athletes that is observed from the values of world-class long jumpers, about 15°–27° (Hay, 1986; Lees et al., 1993; Lees et al., 1994; Arampatzis et al., 1999; Jaitner et al., 2001; Bridgett and Linthorne, 2006; Linthorne, 2008).

When transferring knowledge, the *KBST* suggested that the teacher provides the feedback in the simplest form to help the students focus on areas to improve their long jumps. The results found that *Test 3* shows more improvement in the approach-run phase as a "*Very good*" suggestion from the *KBST* of about 72%; nevertheless, the take-off phase is still "*Fair*" according to the suggestion of three tests. There are several pieces of evidence of transferring knowledge from coaching to improve the athletes' skill from the knowledge management theory (Ray and Ray, 2008; Ennis, 2015; Predoiu et al., 2016; Kendellen and Camiré, 2017).

To support the main contribution of this study, we examined the *KBST* system and method with the ability to capture kinematic data from the long jump student and then processed and analyzed the captured data. In addition, the *KBST* system can be used for transferring experts' knowledge to coaches and long jump students. This method is aimed to overwhelm the difficulties in the traditional coaching technique. Additionally, this method concentrates on creating a low-cost system that measures and analyzes the data from individual long jump students and then gives suggestions to them. The *KBST* system is also easy to set up for calibrating and application.

The study encountered some noise data in the computing methods, such as environmental changes, brightness changes, low-light situation, uncertain moving objects, tree leaves moving, color tracking of the body clothes, and water reflection. Those data could produce much more feature extraction techniques and would also lead to a state extension in the process of analyzing. However, this study's achievement is still in the working process of collecting data from the long jump students, which still needs study cooperation with the Thai National Team long jump athletes for measuring and monitoring performances of each long jump athlete.

There were a few limitations in the study of the *KBST* system. The first is on capturing the volume of the system that depended on the camera positioning; for instance, if the volume of capturing the athlete running around was 50 m, the camera has to be placed at approximately 35–40 m from the athlete's body. So, we have to consider the area for using the *KBST* system. The second is the color of the athlete's suit; according to the real environment, the system is set for detection of just lowering the value of color such as dark gray value and black value. Therefore, the appropriate athlete's suit is dark gray or black color, whereas other colors are restricted to use. Third, the *KBST* system is unable to be captured under a low-light environment situation. It works at normal illumination. In addition, the *KBST* system has to employ assistance capturers for capturing both the running and jumping phases, so the *KBST* simultaneous automatic capturing for two cameras is needed. Finally, the present study used a pre-post design, in which *Test 1* was set as a pre-*KBST* intervention (baseline or control trial) and *Test 2* and *Test 3* were the first and second trials of post-*KBST* intervention, respectively. However, the control group comparison is needed to confirm our findings.

Future studies need to develop an autonomous system for capturing the Thai National Team long jump athletes and for applying the *KBST* system to other kinds of sports.

In conclusion, the *KBST* system is easy to use, cost-effective, and markerless. It offers an alternative approach to capture and analyze the long jump performance of an individual athlete. In particular, the *KBST* system provides suggestion knowledge from experts and is shown to improve all long jump performance parameters from the three long jump tests at six sports schools.

TABLE 4 | The significant difference among the tests of long jump distance performance.

Long jump test		Mean difference	Std. error	Sig.[a]	95% confidence interval for difference[a]	
A	B	(A and B)			Lower bound	Upper bound
Test 1	*Test 2*	−0.207	0.140	0.153	−0.498	0.084
	Test 3	−0.292[b]	0.129	0.034	−0.560	−0.024
Test 2	*Test 1*	0.207	0.140	0.153	−0.084	0.498
	Test 3	−0.085	0.072	0.256	−0.235	0.066
Test 3	*Test 1*	0.292[b]	0.129	0.034	0.024	0.560
	Test 2	0.085	0.072	0.256	−0.066	0.235

Note: Based on estimated marginal means.

[a]*Adjustment for multiple comparisons: least significant difference (equivalent to no adjustments).*

[b]*The mean difference is significant at the 0.05 level.*

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by CMUREC 61/044. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

AUTHOR CONTRIBUTIONS

TK was involved in conceptualization, methodology, system development, evaluation, formal analysis, investigation, data curation, writing of the original draft, and project administration. PK was involved in conceptualization, methodology, investigation, and evaluation. SB was involved in conceptualization, methodology, formal analysis, validation, investigation, data curation, and writing—reviewing and editing. WJ was involved in conceptualization, methodology, formal analysis, investigation, supervision, project administration, and writing—reviewing and editing.

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