Implementation and validity of the long jump knowledge-based system: Case of the approach run phase

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This study aimed to propose the method of implementation of the Knowledge-Based System (KBS) in the case of approach-run phase. The proposed method was implemented for improving the long jump performance of athletes in the approach-run phase. Moreover, this study aimed to examine KBS concurrent validity in distinguishing between professional and amateur populations and then KBS convergent validity against a Tracker video analysis tool. Seven running professionals aged 19 to 42 years and five amateurs aged 18 to 38 years had captured with ten conditions of different movements (C1 to C10) using a standard video camera (60 fps, 10 mm lens). The camera was fixed on the tripod. The results showing an age-related difference in a speed measurement of ten conditions were evidently using the KBS. Good associations were found between KBS and Tracker 4.94 video analysis tool across various conditions of three variables that were the starting position (r=0.926 and 0.963), the maximum velocity (r=0.972 and 0.995) and the location of maximum velocity (r=0.574 and 0.919). In conclusion, the proposed method is a reliable tool for measuring the starting position, maximum speed and position of maximum speed. Furthermore, the proposed method can also distinguish speed performance between professional and amateur across multiple movement conditions.

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Abstract

This study aimed to propose the method of implementation of the Knowledge-Based System (KBS) in the case of approach-run phase. The proposed method was implemented for improving the long jump performance of athletes in the approach-run phase. Moreover, this study aimed to examine KBS concurrent validity in distinguishing between professional and amateur populations and then KBS convergent validity against a Tracker video analysis tool. Seven running professionals aged 19 to 42 years and five amateurs aged 18 to 38 years had captured with ten conditions of different movements (C1 to C10) using a standard video camera (60 fps, 10 mm lens). The camera was fixed on the tripod. The results showing an age-related difference in a speed measurement of ten conditions were evidently using the KBS. Good associations were found between KBS and Tracker 4.94 video analysis tool across various conditions of three variables that were the starting position (r=0.926 and 0.963), the maximum velocity (r=0.972 and 0.995) and the location of maximum velocity (r=0.574 and 0.919). In conclusion, the proposed

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Introduction

Athletic is one of the sports that was contained in the first Olympics in ancient Greece, circa 708B.C. Athletic was divided into two main types as Track and Field. The long jump is one of the sports that was included in the Field of the athletic sports. Long jumpers practise following the long jump biomechanics which includes: the approach-run phase, the take-off phase, flight phase and landing phase to achieve the excellent performance. In order to formulate a good jump, long jumpers have to be a fast runner, muscular legs, a good complex take-off, flight and landing (Linthorne, 2008).

The significant role for improving the action of the individual athlete is the suggestion from coaches and correcting action after athlete finishes each action, for example, Long Jump performs high-speed of run-up, take-off, flight and landing in the pit (Santos & Shannon, 1989; Alexander, 1990; Hay, 1993). In this case, the Human Visual System (HVS) cannot capture all phases of the long jump movement. It might be the reason that why the suggestion and the correction of the individual athlete are somewhat difficult to monitor. Staff coaches need some tools or systems that support them to suggest and correct their athletes.

Computer science and information technology are coming to an influence on measuring athletes' skills, for instance, video analysis software (Bryan, 2004), game analysis tools (O'Donoghue, 2013; O'Donoghue, 2015), sport tracking applications (Oleson et al., 2017; Gade & Moeslund, 2018), human motion tracking (Krzeszowski et al., 2017; Shah et al., 2017), recognition system (Fernandes & Bala, 2016) etc., nevertheless, some systems are difficult to use. And also, some systems are a high cost for procurement. To implement the analysis sport movement tools, the system has to be the user-friendly, the automatic suggestion, the reliable measuring and also the low cost. Computer vision and image processing technologies are still of important role in tools' development for analysing the human movement, recreation and sports as well as skills' training of the athletes (Leo et al., 2017). In addition, the analysis tools for sports still have a wide opportunity to study for improving the movement of the individual athlete.

The knowledge-based system is a part of artificial intelligence (AI) to initiate human knowledge (human expert knowledge in the computer system as called knowledge-based. The Knowledge-Based System (KBS) is a recognition of different human quality, and the knowledge can grow up from experience (Wiig, 1994), then the four main components of KBS which are a knowledge base, an inference engine, a knowledge engineering tool and a particular user interface were determined (Dhaliwal & Benbasat, 1996). Developing the KBS, additionally, is to contain the knowledge engineering and typical software engineering practices (Studer, Benjamins & Fensel, 1998). Furthermore, the KBS comprises technology applications of the organisation that are provided for properties' management of the organisation, for instance, case-based system, rule-based system, expert system and database management system (Laudon & Laudon, 2005). Moreover, the component of KBS is the user interface, intelligent program and a problem-specific database (Becerra-Fernandez & Sabherwal, 2014).

In addition, the challenge of the long jumpers and their coaches is the position of the maximum speed during each long jumper performing an approach-run before taking-off. To generate the longest distance, the long jumper is to produce a maximum of the speed approximately the last 2–3 strides or about 5 m, because it has a strong influence on an athlete's long jump performance (Bridgett, Galloway & Linthorne, 2002). Fast speed movement, moreover, the position of the maximum speed, as well as the instantaneous speed are more problematic to detect with the Human Visual System (HVS). Including, a stopwatch that it has been a useful measurement tool for capturing total speed of running. However, those still have numerous errors of the detection of maximum speed during running. It might be human errors during measuring. Those problems lead to the research question as: "How to detect the instantaneous speed and position of the maximum speed of the athlete?"

Therefore, the combination of computer science, information technology and the knowledge-based system might be possible to be alternative tools for assistant coaches to improve the athletes' performance. Besides, it might also to be detection speed tools for measuring speed performance of long jumpers. In this study, we aim at implementing of the proposed method for the long jump knowledge-based system (KBS): the case of approach-run phase due to the fact that the approach-run is essential to acquire for the long jump distance (Lees, Fowler & Derby,1993; Lees, Graham-Smith & Fowler, 1994; Bridgett, Galloway & Linthorne, 2002; Bridgett & Linthorne, 2006). Data collection was made in Chiang Mai province, the north of

Thailand. Additionally, the convergent validity of the KBS against the Tracker video analysis tools was evaluated.

The contribution of this paper to the literature, this paper contributes to developing of the knowledge-based system (KBS): Case of approach-run phase, and also, analysing of the correlation of the maximum speed, the position of maximum speed and starting position between the KBS and a video analysis software tool.

In the previous works, there are several researchers who studied computer sciences in sports. Some works have analysed the performance of long jump athletes. Some studies have developed a tool for analysing the athlete's movement as follows. Theodorou and his colleagues 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 (Casio EX F1) operating at 300 fps. The videos were digitised using APAS 13.3.0.3 of Ariel Dynamics, Inc., Trabuco Canyon, CA) (Theodorou et al., 2017). Scott and his colleagues studied the comparison between non-long jumpers and experienced long jumpers of a similar pattern of variability in footfall placement between trials. The approach-run phase of each long jumper was recorded using a video camera (Panasonic F-15) operating at 25 Hz. The manually-panned capturing was performed to record then run-up was digitised using an Arvis digitiser and an Archimedes 440 microcomputer for analysing (Scott, Li & Davids, 1997). Jaitner and his colleagues examined the transition from the approach-run to the take-off, using Time-Continuous kinematic data of the long jump technique. The intricate movement patterns were categorised using the single linkage algorithm with 57 trials (4.45-6.84 m) of time-continuous data (Jaitner, Mendoza & Schöllhorn, 2001). Hsu and his colleagues proposed the process of an automatic motion detection during a standing long jump. All frames of jumper videos sequence were segmented using background subtraction technique, and then, the features of all video frames were extracted using the Pose estimation and the Hue-Saturation-Value (HSV) space. After that, the genetic algorithm based (GA-based) was used to learn joints of the person. The results showed that the proposed process could generate joints of the person (Hsu et al., 2006). Panagiotakis and his colleagues developed the automatic human detection, tracking and action recognition based on real and dynamic environments of athlete finding. The athlete videos were segmented using the Temporal Signal segmentation, and then the Human Points Detection algorithm was used for the feature extraction. Silhouette analysis algorithm was performed for classifying types of sport such as pole vault, high jump, long jump and triple jump. The results demonstrated that the accuracy classification rates were very good (Panagiotakis, Grinias & Tziritas, 2006). Dubois and his colleagues employed an image processing technique to measure the swimming biomechanics. A freestyle swimming video footage was analysed using an image processing technique. Both arms and legs were automatically detected and then analysed to improve an individual athlete movement. The Normalised Cuts techniques were employed in the segmentation, and then Global Probability of Boundary was used in the feature extraction (Dubois, Thiel & James, 2012).

Tracker Video Analysis and Modelling Tool (Tracker 4.94) is one of the video analysis tools for plotting position, velocity, acceleration and other functions. Moreover, a Tracker video analysis software is a free Java video analysis and modelling tool from Open Source Physics (Tracker, 2018). There are several works to analyse the video sequence using a Tracker video analysis software, for example, Tinoco and his colleagues proposed the analysing time and motions in a manual process using a capture motion system. IR passive markers were located on the hands to take the position of each one. Tracker was employed to determine the locations of the makers of the projective plane (Tinoco et al., 2015). Gillinov and his colleagues used Tracker to analyse four outcomes such as Foot strike, Ground contact time, Stride cadence and Knee flexion angle. After that traditional shoes, minimalist shoes and barefoot (socked) running facilitated a midfoot or forefoot strike in the group of experienced high school runners were compared (Gillinov et al., 2015). Lara-Barrios and his colleagues analysed displacement and velocity graphs from videos using a Tracker for testing flexion of a lower-limb (Lara-Barrios et al., 2017). Besides, Barraza and his colleagues investigated the kinetic differences between proficient and non-proficient players during throw-in of the soccer players. Tracker was used for tracking the kinematics data such as the peak angle for the hip, knee, ankle, shoulder, elbow and wrist (Barraza & Yeow, 2015). Hence, a Tracker video analysis tool was selected as a standard tool for tracking distance, velocity, angle, etc., in this study.

According to the requirement analysis of the Knowledge-Based System for training long jump was investigated and designed from the long jump experts (Kamnardsiri et al., 2018). One of the majorities of coaches' requirement is the system for measuring instantons speed and also the position of the maximum speed of the long jumper. Moreover, knowledge form long jump experts are to be transferred to coaches and athletes as well.

Therefore, the Knowledge-Based System for long jump training (KBS): the approach-run phase was implemented for detection of the starting position, the maximum velocity (V_{max}) and the maximum velocity's position ($V_{maxPosition}$) of the long jumper.

Figure 1.JPEG

To develop the system of the approach-run phase, our proposed method was produced using Matlab R2015a in combination with the Image Processing Toolbox and the Computer Vision System Toolbox. The proposed method is shown in (Fig. 1).

Video motion capture

In this stage, the participants ran with ten conditions of this study on the long jump track. A video sequence was captured using a standard video camera, and also the camera was set on a tripod.

Motion segmentation

To segment images into foreground and background regions, the captured video sequences were recorded as the original size 1280×720 pixels and then the videos were transformed to grayscale images $I_{index(x,y)}$ as intensity image: the value as 8-bit images [0,255]. Furthermore, the background subtraction method was used for splitting the long jumper from the background. The threshold ($\tau = 60$) was employed to reject noises caused by shadows shifting, brightness changing, etc. Subtraction value of each pixel $I_{binary(x,y)}$ was determined as 'background': difference value close to zero while 'foreground': large difference values. A binary image $I_{binary(x,y)}$ was given by Equation 1.

$$I_{binary}(x,y) = \begin{cases} 1 & \text{if } I_{index}(x,y) > \tau \\ 0 & otherwise \end{cases} \quad (1)$$

Feature extraction

To track the motion of the human movement, the centroid of the human body or the body's centre of mass (COM) was focused to make the reference point for all calculations such as distance, velocity, maximum velocity, etc. To define the centroid of the moving region, the centroid was determined as COM of two dimensional planar lamina (Bai & Breen, 2008). The COM of the human body: $Body_{position(x_{cm}, y_{cm})}$, x_{cm} and y_{cm} of n point masses mi located at positions x_i and y_i was given by Equations (2-4).

$$x_{cm} = \frac{\sum_{i=1}^{n} m_i x_i}{M} \qquad (2)$$

and

$$y_{cm} = \frac{\sum_{i=1}^{n} m_i y_i}{M} \qquad (3)$$

where,

$$M = \sum_{i=1}^{n} m_i = total\ mass \qquad (4)$$

Figure 2.JPEG

Fig. 2. illustrates the processing results of both the motion segmentation stage and the feature extraction stage that were performed to track the maximum speed, the starting position and also the maximum speed position of the human for the approach-run phase. After the COM was located, the next stage was the detection of both the Starting position and the Maximum velocity.

Starting position and Velocity (v) detection

To detect the starting position and the velocity (v) of each step of time (Timestep), the body's centre of mass (COM) of x axis (x_{cm}) was considered in the proposed method because it was horizontal velocity detection. The take-off position ($Takeoff_{positon}$) was obtained for calculating the body position ($Body_{position}$) of the long jumper that the starting position ($Strating_{position}$) was given by Equation 5.

$$Starting_{position} = Takeoff_{position} - Body_{position} \qquad (5)$$

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And also, the velocity (v) of each step of time (Timestep) was given by Equations (6-8).

$$v_{index} = \frac{\Delta x_{index}}{\Delta t_{index}} \quad (6)$$

where,

$$\Delta x = x_{index + Timestep} - x_{index} \quad (7)$$

and

$$\Delta t = t_{index + Timestep} - t_{index} \quad (8)$$

Maximum velocity (Vmax) and Maximum velocity position (VmaxPosition) detection

The maximum speed of the human running or the maximum velocity (Vmax) and the maximum velocity position were detected for finding the exact position of starting position of the athlete for each long jumper. The maximum velocity (Vmax) of the runner was given by Equation 9.

$$(V_{max}, index) = max(v_{index=1}, v_{index=2}, \ldots, v_{index=n}) \quad (9)$$

and the maximum velocity (VmaxPosition) was given by Equation 10.

$$V_{maxPosition} = Body_{position}(index) \quad (10)$$

Knowledge experts' approach-run phase rules

According to experts' conditions, experts: who passed the training IAAF Level III (IAAF, 2018). They suggested that rules of the approach-run phase separated into 3 rules. To generate the longest distance, the long jumper has to produce the maximum of velocity (V_{max}) around at the 1[st] rule (the last 2 to 3 strides or around 5 meters before take-off).

Fig. 3. shows rules of the approach-run phase. Three rules were determined to produce rule-based (inference engine) for correcting the long jump running.

Figure 3.JPEG

Materials & Methods

Participants

Seven long jump professionals aged 19 to 42 years and five amateurs aged 18 to 38 years participated in this study. Long jump professionals and Amateurs were recruited from Chiang Mai University Athletic Club from Chiang Mai University, Chiang Mai province, Thailand. Inclusion criteria is: 1) Thai national healthy long jump athletes age 15-50 years, 2) able to do fast running 25-30 meters and jump into the sand pit, and 3) able to comprehend instructions and willing to participate. Exclusion criteria is: 1) presence of physical conditions such as a musculoskeletal injury that preclude participants in completing the testing protocol, 2) taking alcohol 6 hours before testing or using drug regimens that affect running performance. This study was approved by the Chiang Mai University, Research Ethics Committee, Chiang Mai, Thailand (CMUREC 61/044). All of the participants provided informed consent from their parent prior to participation.

Protocol

In the approach-run phase, assessments of the Starting position, the Maximum velocity (V_{max}) and Maximum velocity's position ($V_{maxPosition}$) were performed for a total of all conditions on the synthetic running track, flat and dry.

Figure 4.JPEG

Fig. 4. illustrated the protocol of the approach-run phase that consisted of 4 located markers as follows; M_1: at the starting point of the long jump sand pit, M_2: at the take-off position, M_3: at the 5 meters far from the take-off position and M4: at the 10 meters far from take-off position. The position of the camera far from the take-off position (M_2) around ten meters and 18-20 meters from the marker (M_4). The camera was fixed on the tripod and 3-way head which height from the floor around 1.5 meters. Additionally, each participant wore a black sports long-sleeved shirt and a black sport jogger pant. The passive circular marker 2 inches of the diameter size was

then placed at the body's centre of mass (COM) of all participants for processing in Tracker 4.94. Materials of the study are shown in Table 1.

Table 1.PDF

Procedures

This study focuses on the validity of the proposed method in the approach-run phase of the long jump biomechanics. Fig. 5. illustrated the procedure diagram of this study. The procedure comprised; Firstly, Recruitment of the participants from Chiang Mai University, Chiang Mai, Thailand. Secondly, the participants performed ten condition C1-C10, and the standard video camera was used for capturing the motion of participants. Thirdly, both the proposed system and Tracker 4.94 were employed to analyse and detect variables such as Starting position, Vmax, Vmax position. Finally, the association between each variable of both systems were calculated.

Figure 5.JPEG

Data collection

The approach-run of participants was recorded with a stationary video camera (Nikon 1 J1) at the rate of 60 frames/second and 10 mm lens in a MOV video format. All videos were set at a resolution of 1280 × 720 pixels. The participant performed one trial of each condition with ten conditions which are listed in Table 2.

Table 2.PDF

Data analysis

The 120 videos (.MOV format) collected from the video camera were transferred to a personal computer. These videos were then analysed by the knowledge-based system for long jump training (KBS): the approach-run phase and also Tracker 4.94 video analysis software. The variables such as starting position, the maximum velocity (Vmax) and the position of maximum velocity (VmaxPosition) were calculated using the KBS algorithm and also the Tracker 4.94 video analysis software. Additionally, Statistical analysis

Statistical analyses were performed using IBM SPSS Statistics 21 for Windows (SPSS Inc., Chicago, IL, USA) with analysis of data, $p<0.05$ was considered as statistically significant. Descriptive statistics (means, SD and variance) were calculated for the participants' demographic characteristics. To examine the different performance between groups, the maximum velocity (Vmax) was examined using a nonparametric statistical test (the Mann-Whitney-U test) for the difference between the professional's group and the amateur's group. Moreover, to examine the KBS: approach-run phase validity against the Tracker 4.94 video analysis software, Pearson product-moment correlation coefficients method was employed for calculating the relationship of each condition.

Results

Descriptive statistics

Twelve participants successfully completed the approach-run of all conditions without incident. The participants' demographic characteristics and indicates that the sample of this study comprised relatively healthy groups of gender (6 males and 6 females) and status (7 professionals and 5 amateurs) without cognitive impairment. The average age is 27.58 years (SD=9.67, Variance=93.53). The average weight is 61.08 kg (SD=12.36, Variance=152.81). The average height is 1.70 m (SD=0.07, Variance=0.01). The average Body Mass Index (BMI) is 17.89 kg.m-2 (SD=3.18, Variance=10.14).

The performance differences between groups

Statistical comparisons between the professional's group and the amateur's group were conducted with the Mann-Whitney U tests for continuous variables. Table 3 lists the significant group differences of the maximum velocity (V_{max}) form the KBS of each condition (C1-C10) between the professional and the amateur groups. The result shows that both the condition C5 and the condition C10 were most significantly different to professional at $p< 0.01$ whereas the condition C2 was least significantly different to professional at $p < 0.05$.

Table 3.PDF

The KBS: approach-run system validity

Table 4 presents Pearson correlation coefficients between KBS and Tracker data of each condition (C1-C10). The KBS measures were reasonably strongly associated with Tracker 4.94 measures, with correlation coefficients between 0.926 and 0.963 of starting position, correlation coefficients between 0.972 and 0.995 of maximum velocity (Vmax) and correlation coefficients between 0.574 and 0.919 of the position of maximum velocity (VmaxPosition). Especially, the KBS had excellent correlation with Tracker 4.94 for the maximum velocity of approach-run measure, with correlation coefficients greater than 0.972 across all conditions.

Table 4.PDF

Discussion

The results of this study demonstrate that the proposed system for the long jump knowledge-based system (KBS): the case of approach-run phase can be used to detect the instantaneous speed of both professional and amateur participants of each condition as shown in Table 3 and Table 4. Moreover, the results show that the proposed system can be used for detecting the maximum speed, that it answers the research questions as “How to detect the instantaneous speed and position of the maximum speed of the athlete?”

Our finding of this study is the detection of the instantaneous speed, maximum speed and position for the long-distance about 25-30 m that is useful for measuring speed and maximum speed position of the long jumper in the approach-run phase.

In this study, the proposed system has numerous advantages. The first advantage is that the proposed system provides semi-automatic detection. The system will immediately show the results after data processing is finished. The second advantage is long-distance for capturing an approach-run of a long jump athlete. The third advantage is that the proposed system easily setup and also participants do not necessarily place more markers in the body.

However, the proposed system had several limitations. The first limitation is the frame rate of a standard video camera (60 Hz). In the implementation of the KBS, selecting a standard video camera is one of the essential things in the motion capture process so the reasons for the resolution of a video, frame rate, length of a camera lens, distortion of images, files format of a video, etc., need to be considered. Our suggestion to collect data is the selection of a high-speed camera such as 120 Hz or 240 Hz and Full frame resolution for implementing the system. The second limitation is the environmental change. Motion segmentation and feature extraction are very vital to track speed, distance and maximum speed position of a human movement. The serious problems of the environmental change such as sky brightness, moving shadow, tree leaves, moving small objects and moving cloud and colour of the shirt need to be solved for tracking the COM of a human's body. In this study, a black suit was worn to reduce the problems of the environmental change in motion segmentation and feature extraction of the implementation process.

Maximum velocity position of approach-run is the primary goal of the long jump biomechanics. The KBS: approach-run phase provides the tracking measurement of the human's movement such as starting position, maximum velocity (Vmax) and also the position of maximum velocity (VmaxPosition). To validate the system, the Tracker video analysis tool that provides the tracking measurement as a standard system for testing the validity of the proposed method was used. The KBS: approach-run phase is able to detect the starting position with correlation coefficients greater than 0.926 across all condition ($p<0.01$) and able to track human speed with correlation coefficients greater than 0.972 across all conditions ($p<0.01$). The system is able to determine the position of maximum velocity with correlation coefficients greater than 0.574 across all conditions ($p<0.05$), nevertheless, the results indicated that the condition C7 had not a significant relationship due to C7 is "Running at medium speed, then gradually decreasing speed and walk" but almost long jump athletes always use high speed for the approach phase. They do not use a medium speed condition for the approach-run phase. Hence, we can discard this condition.

In the conditions for long jump biomechanics, C8: "Running at medium speed, then gradually increasing to fastest speed" and C10: "Running at the fastest speed from the beginning to the end" is suitable for approach-run. The results revealed that KBS measure which determined the position of maximum velocity (VmaxPosition) of both C8 and C10 had excellent correlation with Tracker 4.94 measure, with correlation coefficients $r=0.778$ and $r=0.870$, the significant relationship ($p<0.01$).

Conclusions

In this study, we have implemented KBS: approach-run phase of the long jump biomechanics and then the system has been validated using standard video analysis and modelling tool. For data collection, 120 videos from a standard video camera were captured with ten conditions (C1-C10) of each participant.

The proposed method enables measurement of starting position, maximum speed and position of maximum speed that is simple and less expensive than methods using motion capture or high-speed camera system. This study has found the proposed method to be a reliable measure of starting position, maximum velocity (V_{max}) and also the position of the maximum velocity ($V_{maxPosition}$).

Due to the participants in this study were runners that they were recruited for testing the validity of the proposed system only approach-run phase. The participants in this study, especially, professionals had good performance for fast running that they can perform agent long jumper in the approach-run phase. Additional, In the near future, our works will be studied in long jumpers of sports school in Thailand which they are students who interest at the long jump, and then suggestion system and the inference engine of the Knowledge-Based System (KBS) will be generated. The KBS should be used for training long jump. An automated suggestion system, furthermore, should be included in the KBS for giving a user-friendly system.

In the future works, furthermore, this implementation of the proposed method could be applied to develop the digital game-based training in education, such as Game-Based Learning, Serious Game, Gamification, Modelling and Simulation in Sports and Health, etc., for improving students' long jump techniques.

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Table 1(on next page)

Table 1: Materials for motion capture in this study

Table 1 Materials for motion capture in this study

Material	Type
Camera	Nikon 1 J1 video camera with 10-30 mm. lens
Tripod	Tripod and 3-way head
Floor markers	Floor markers M1, M2, M3 and M4
Passive marker	Circular marker 2 inches of the diameter size
Shirt	Black sport long-sleeved shirt
Pant	Black sport jogger pant
Video analysis software	Tracker 4.94 Video Analysis and Modelling Tool (open source physics software)

Table 2 (on next page)

Table 2: Ten conditions (C1-C10) for each participant.

Table 2 Ten conditions (C1-C10) for each participant

Condition	Description
C1	Walking at a comfortable speed from the beginning to the end
C2	Jogging from the beginning to the end
C3	Jogging and then gradually increasing speed
C4	Jogging and then gradually decreasing speed
C5	Running at medium speed from the beginning to the end
C6	Running at medium speed and then gradually increasing speed
C7	Running at medium speed, then gradually decreasing speed and walk
C8	Running at medium speed, then gradually increasing to fastest speed
C9	Running at the fastest speed, then gradually decreasing speed
C10	Running at the fastest speed from the beginning to the end

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Table 3(on next page)

Table 3: Comparison of the maximum velocity (m/s) for professional and amateur participants of each condition.

Table 3 Comparison of the maximum velocity (m/s) for professional and amateur participants of each condition

Condition	Professional (n=7) Mean (SD)	Amateur (n=5) Mean (SD)	P-value
C1	1.65 (0.13)	1.31 (0.25)	.030*
C2	2.86 (0.42)	2.26 (0.43)	.048*
C3	4.98 (0.81)	3.44 (0.70)	.018*
C4	3.05 (0.48)	2.21 (0.53)	.018*
C5	5.40 (0.45)	3.10 (0.38)	.003**
C6	6.16 (0.55)	4.27 (0.88)	.010*
C7	4.49 (0.66)	3.00 (0.36)	.005**
C8	6.38 (1.02)	4.49 (0.97)	.030*
C9	6.22 (0.55)	4.60 (0.55)	.010*
C10	6.85 (0.99)	4.93 (0.70)	.003**

Note: **significantly different to Professional ($p< 0.01$);
*significantly different to Professional ($p< 0.05$)

Table 4(on next page)

Table 4: The correlation between the proposed System and Tracker 4.94.

Pearson correlation coefficients (r) between the Knowledge-Based System for long jump training and Tracker 4.94 video analysis and modelling tool (N=12).

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Table 4 Pearson correlation coefficients (r) between the Knowledge-Based System for long jump training and Tracker 4.94 video analysis and modelling tool (N=12)

Condition	Starting position (m)			V_{max} (m/s)			$V_{maxPosition}$ (m)		
	KBS Mean (SD)	Tracker 4.94 Mean (SD)	r (95% CIs)	KBS Mean (SD)	Tracker 4.94 Mean (SD)	r (95% CIs)	KBS Mean (SD)	Tracker 4.94 Mean (SD)	r (95% CIs)
C1	20.96 (1.80)	20.32 (1.61)	0.956** (0.908-0.988)	1.51 (0.25)	1.56 (0.27)	0.985** (0.946-0.997)	13.68 (4.59)	11.90 (3.73)	0.801** (0.524-0.956)
C2	20.93 (1.97)	20.26 (1.81)	0.952** (0.931-0.986)	2.61 (0.51)	2.66 (0.55)	0.991** (0.974-0.998)	9.18 (4.39)	9.02 (3.98)	0.834** (0.441-0.965)
C3	20.70 (1.90)	20.17 (1.60)	0.961** (0.946-0.993)	4.34 (1.08)	4.39 (1.11)	0.989** (0.977-0.998)	5.65 (2.56)	3.91 (1.82)	0.652* (0.256-0.869)
C4	20.73 (1.74)	20.15 (1.62)	0.935** (0.878-0.976)	2.70 (0.64)	2.72 (0.70)	0.993** (0.982-0.999)	12.90 (2.22)	12.12 (2.73)	0.919** (0.841-0.968)
C5	20.68 (1.64)	20.07 (1.45)	0.926** (0.794-0.981)	4.44 (1.25)	4.47 (1.24)	0.994** (0.986-0.998)	8.55 (2.26)	6.66 (2.95)	0.725** (0.362-0.887)
C6	20.91 (1.85)	20.25 (1.77)	0.941** (0.869-0.979)	5.37 (1.18)	5.37 (1.24)	0.980** (0.962-0.994)	6.04 (2.37)	4.71 (1.93)	0.715** (0.201-0.971)
C7	21.03 (1.93)	20.35 (1.83)	0.952** (0.873-0.986)	3.87 (0.93)	3.90 (0.93)	0.995** (0.987-0.998)	14.49 (1.71)	13.15 (1.39)	0.574 (0.029-0.887)
C8	20.85 (1.65)	20.36 (1.58)	0.963** (0.938-0.992)	5.59 (1.36)	5.62 (1.37)	0.972** (0.937-0.996)	5.44 (2.13)	3.95 (2.18)	0.778** (0.464-0.937)
C9	21.04 (1.81)	20.39 (1.62)	0.938** (0.911-0.978)	5.55 (1.16)	5.58 (1.08)	0.989** (0.978-0.997)	12.73 (1.44)	10.89 (1.88)	0.650* (0.087-0.888)
C10	20.95 (2.07)	20.46 (1.75)	0.959** (0.859-0.995)	6.05 (1.30)	6.13 (1.24)	0.988** (0.975-0.996)	7.66 (1.89)	5.86 (2.59)	0.870** (0.612-0.971)

*Note: **significant relationship to Tracker (p< 0.01);*
**significant relationship to Tracker (p< 0.05);*

Figure 1

Figure 1: System flow of the proposed method.

The proposed method comprises six stages that are (1) Video motion capture, (2) Motion segmentation, (3) Feature extraction, (4) Starting position and Maximum velocity detection, (5) Maximum velocity position detection and (6) Knowledge experts' suggestion.

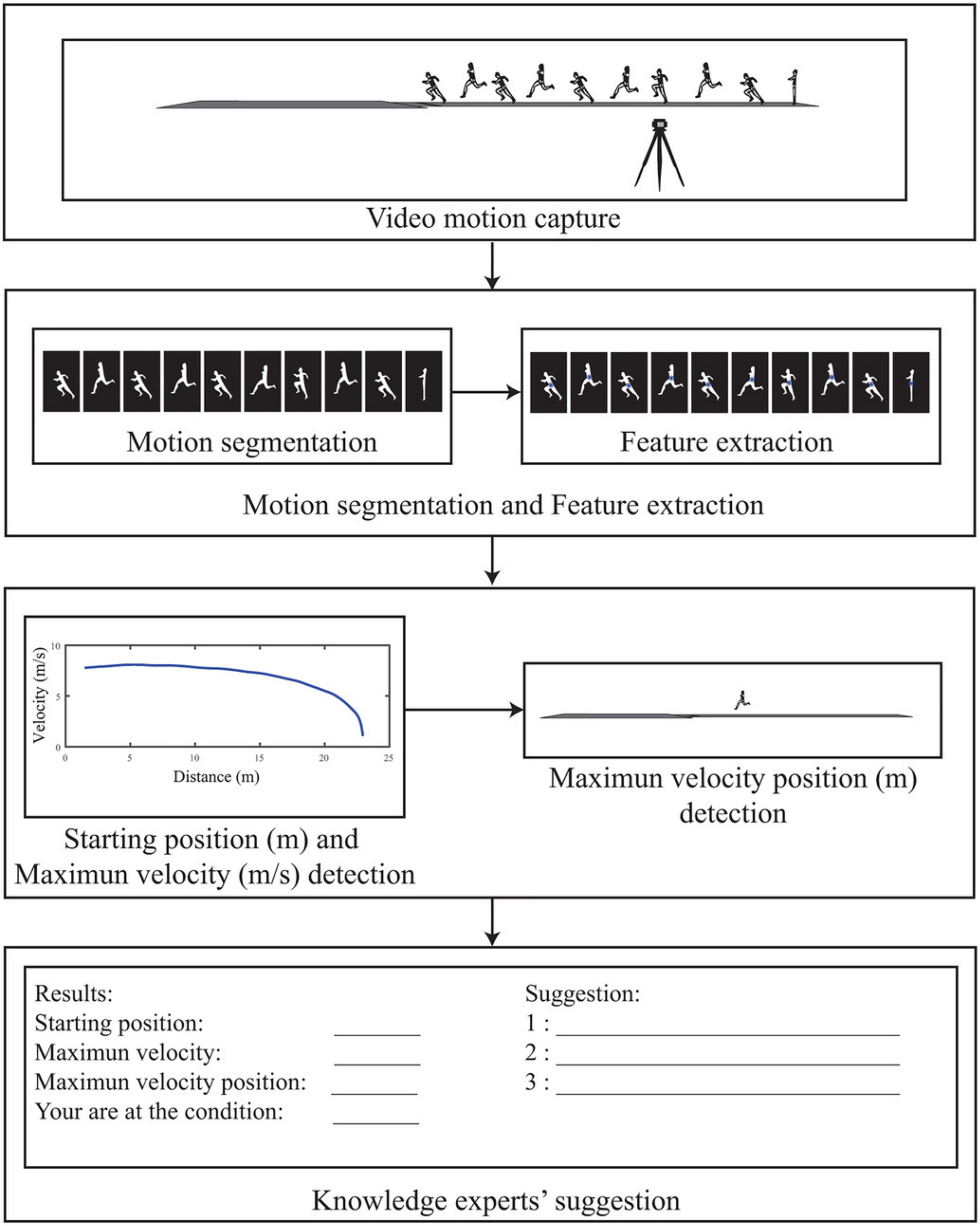
Video motion capture
Motion segmentation
Feature extraction
Motion segmentation and Feature extraction
Velocity (m/s)
Distance (m)
0
5
10
15
20
25
Starting position (m) and
Maximun velocity (m/s) detection
Maximun velocity position (m)
detection
Results:
Starting position:
Maximun velocity:
Maximun velocity position:
Your are at the condition:
Suggestion:
1 :
2 :
3 :
Knowledge experts' suggestion

Figure 2

Figure 2: Motion segmentation and Feature extraction.

(a) background, (b) foreground, (c) background subtraction and (d) adaptive background subtraction with the body's centre of mass (COM) detection.

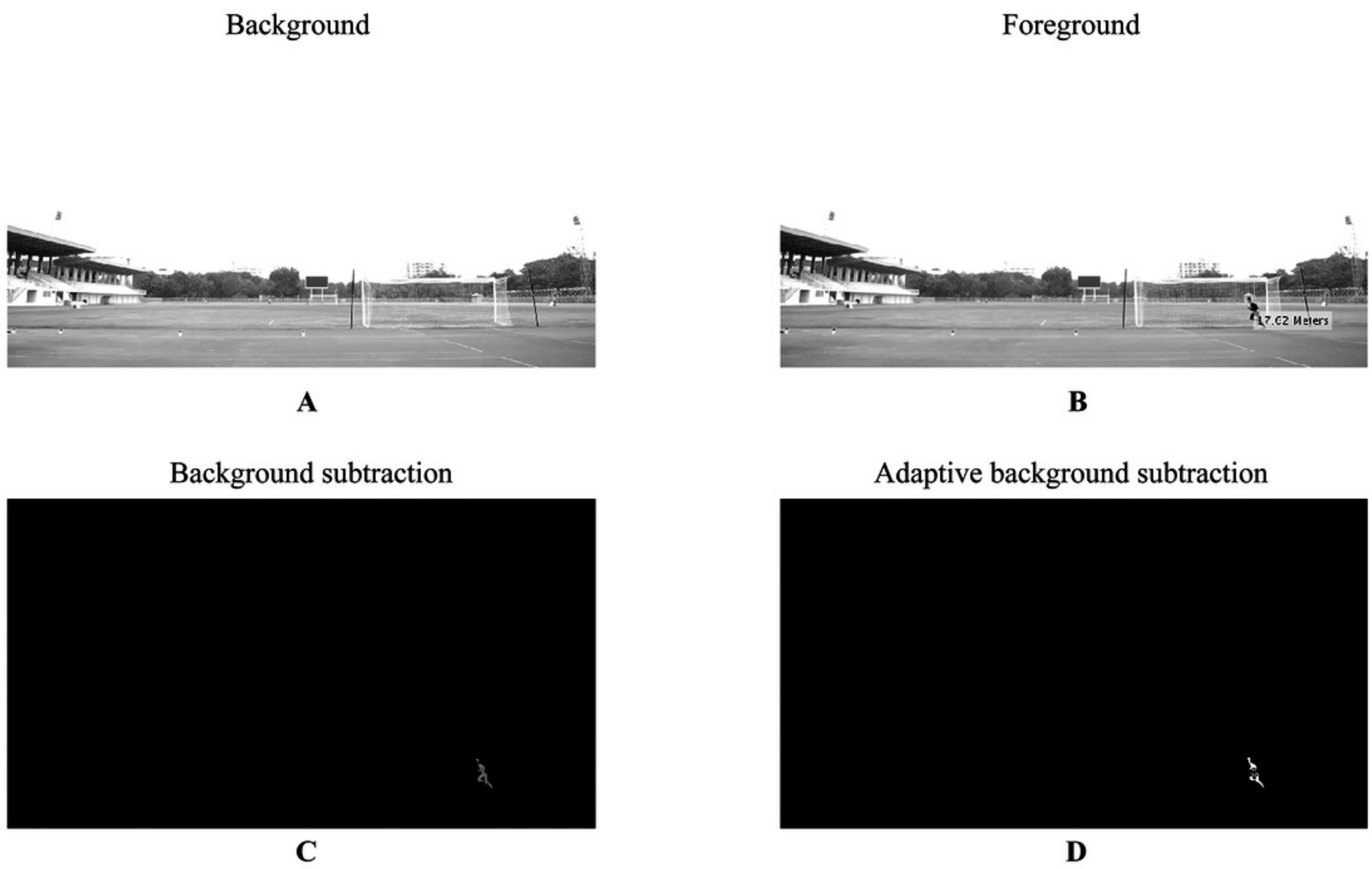

Figure 3

Figure 3 Three rules of the approach-run phase.

1st rule at the take-off board to around 5 meters from the take-off board (around the last 2 to 3 strides), 2nd rule at 5 meters from the take-off board to 10 meters from the take-off board and 3rd rule at 10 meters from the take-off board to the starting position.

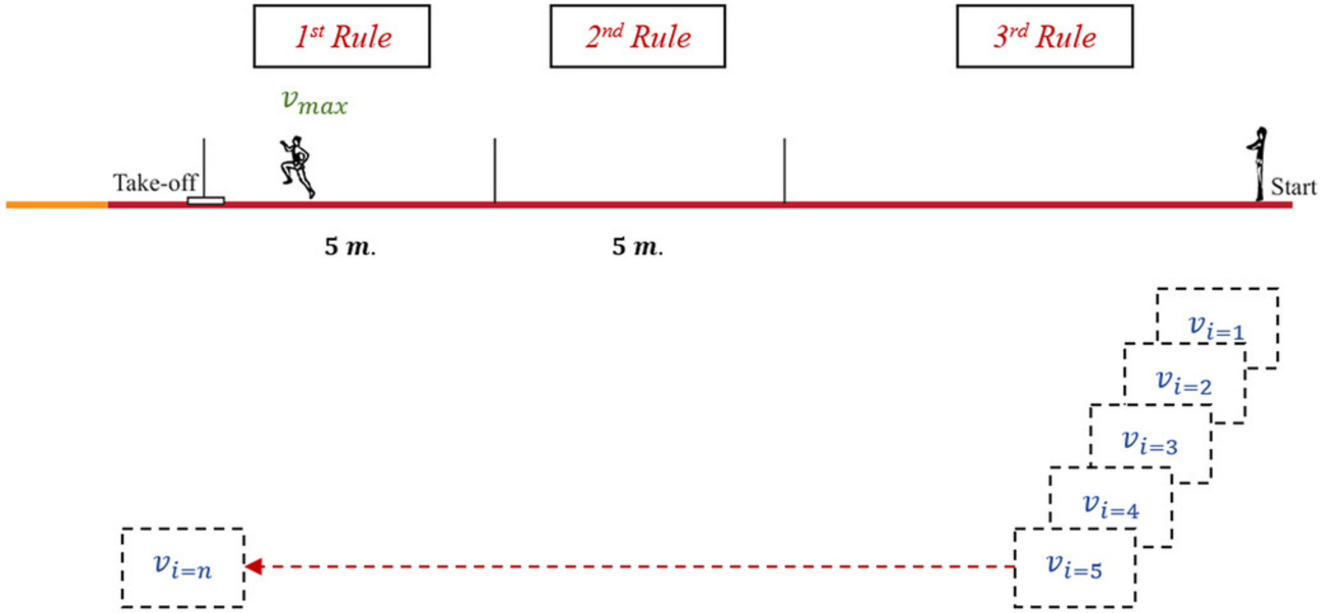

Figure 4

Figure 4: The protocol of the approach-run phase in the long jump.

Markers: M_1 at the long jump sand pit, M_2 at the take-off board, M_3: at the 5 meters from the take-off board and M4: at the 10 meters from take-off board. The camera was fixed on the tripod.

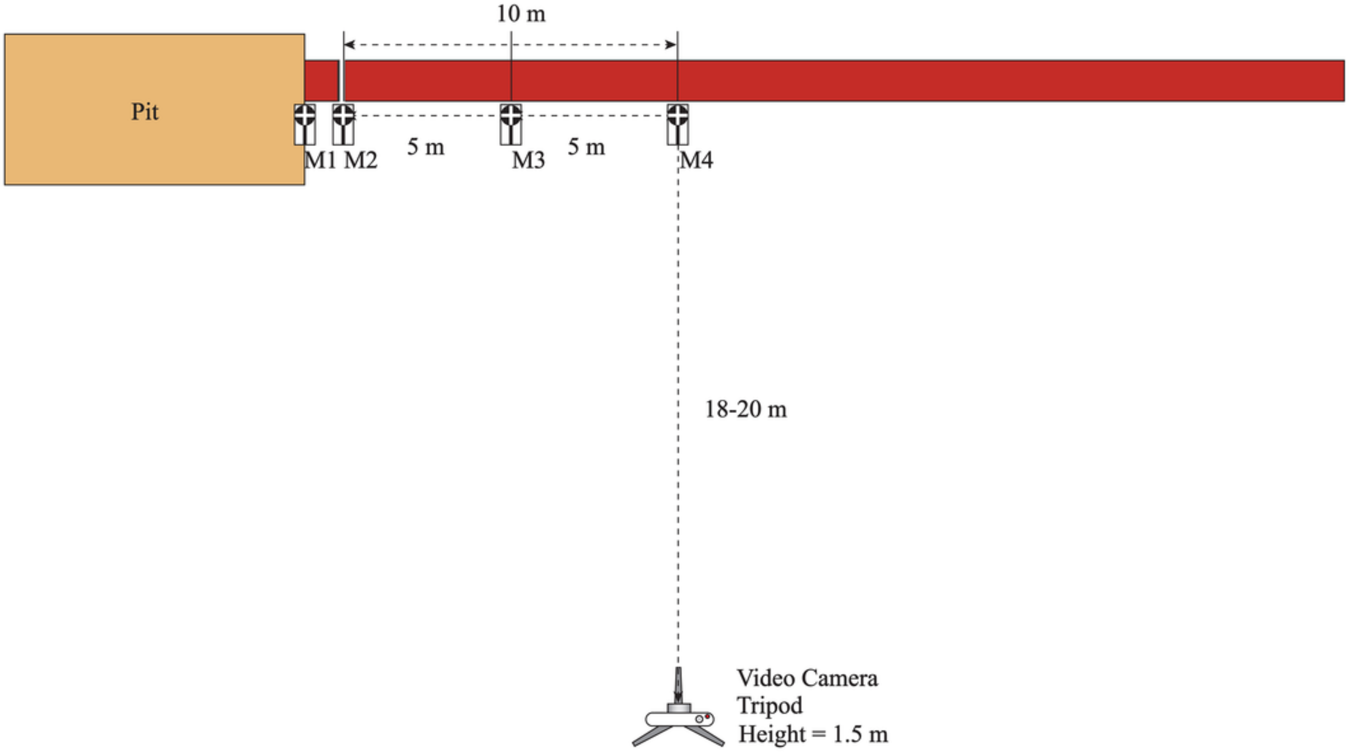

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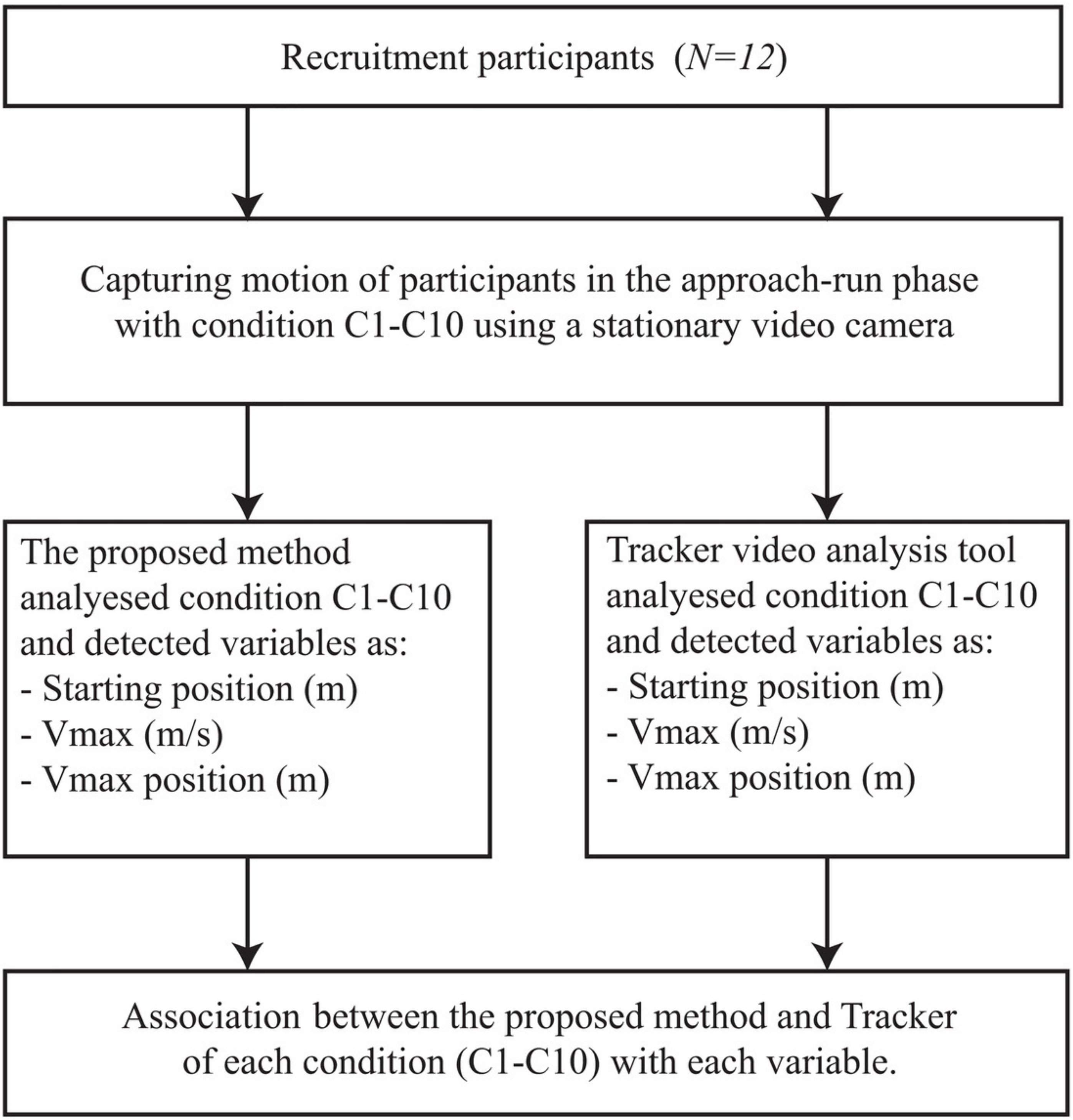
Figure 5

Figure 5 The procedure diagram of the validity of the proposed method for the approach-run phase of the long jump.

The diagram consists of recruitment of the participants, capturing the motion of participants, detecting variables such as Starting position, Vmax, Vmax position and the association between each variable of both systems.


Recruitment participants (N=12)
Capturing motion of participants in the approach-run phase with condition C1-C10 using a stationary video camera
The proposed method analysed condition C1-C10 and detected variables as:
- Starting position (m)
- Vmax (m/s)
- Vmax position (m)
Tracker video analysis tool analysed condition C1-C10 and detected variables as:
- Starting position (m)
- Vmax (m/s)
- Vmax position (m)
Association between the proposed method and Tracker of each condition (C1-C10) with each variable.