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Movement Balance Evaluation for Basketball Training Through Multi-Source Sensors

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ABSTRACT

Balance ability is the basic sports quality of athletes. For basketball players, balance training includes take-off, turning, confrontation, shooting, landing, and other links. If the players have good balance ability, they can effectively prevent sports injury and competition interference and improve the performance of basketball competition. This paper adopts the acceleration signals from multi-source sensors to evaluate movement balance for basketball training. First, acceleration signals are collected by acceleration sensors to depict the basketball player's actions. Second, the hidden Markov model is used to describe the change or transfer of different states during player's actions. Third, the acceleration signal and observation sequence from hidden Markov are used to determine whether the player is under imbalance state. The effectiveness is evaluated on a private dataset.

KEYWORDS

Movement Balance Evaluation, Skeleton Information, Training Auxiliary System, Video Content Analysis

1. INTRODUCTION

The confrontation is one of the main characteristics of modern basketball (Liu 2018). Defensive consciousness and ability of athletes can be improved with the development of basketball skills and tactics under continuous revision of game rules. It makes athletes have more frequent physical contact in the competition (Pang 2020; Jin 2019). The physical confrontation becomes more and more intense, which puts forward higher requirements for athletes to use offensive technology. The body balance of offensive technology in basketball can help us better understand the internal law of basketball attack technology and make the offensive technology be rational and effective (Xiao 2020; Daniel et al. 2017).

The movement is a key aspect in basketball training and competition. Basketball technical movement includes linear movement, angular movement and compound movement of human body or ball. From the perspective of body balance, it includes static balance and steady-state balance (Gebel et al. 2020; Lee et al. 2021). During playing basketball, the displacement relative to the human body

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and the posture of the human body remain unchanged in a certain time. The balance is a kind of static state, termed as static balance. Under the condition of confrontation or no confrontation, in order to achieve technical effect or tactical purpose, athletes change body posture and position according to space-time conditions, connect and combine several technical actions, and timely adjust the center of gravity and inertia to maintain body balance, which is a kind of dynamic steady-state balance. The body balance of offensive technology is a process of mutual transformation between static and steady state. It is a cyclic process from balance to break balance and then to achieve new balance.

According to the principle of mechanics (Chakraborty & Mondal 2020; Bahlakeh et al. 2017), the necessary conditions for human body balance are that the combined external force is zero and the resultant moment is zero. In addition, the body balance also depends on the support surface, the height of center of gravity and the relative position of the center of gravity projection line on the support surface (Ghislieri et al. 2019; Baige et al. 2020). The support surface is the plane between two feet. The larger the support surface is, the greater the stability of the body is. For the height of the center of gravity, the lower the center of gravity is, the greater the stability is. The relative position of the center of gravity projection line on the support surface is stable between the two feet. According to the characteristics and internal laws of basketball sport, the posture of static balance should satisfy the distance between the front and back of the two feet is close to the same width as the shoulder, the angle between the two knees is bent, the angle between the big legs is about 135°, the angle of the ankle joint is about 70 °, the front sole of the foot touches the ground, the head remains stable, the projection point of the center of gravity falls between the two feet and the upper body leans forward slightly. It does not only maintain good stability and balance in confrontation, but also can move horizontally or take off in all directions in time. Steady state balance is the unity of balance in motion (Reimann et al. 2018). It reflects in the free and consistent connection between several technical movements. The basketball player should actively seize the ground and space, adjust the center of gravity in time, and keep coordination of head, upper limbs and trunk.

In the offensive technology (Wu & Bornn 2018; Jia 2018), the body balance is a complete system, which includes the standardization of single technology and the coherence of the connection of combined technology, comprehensiveness of observation and accuracy of judgment, antagonism of technical action, and psychological stability.

Basketball offensive technology refers to the practical action and the combination of actions with offensive effect (Demenius 2020). Single technical action is the basis of combined technical action. The application of each single technical action has certain requirements such as sequence, direction, route and timing. Its action structure is suitable for the principles of human sports anatomy and sports biomechanics. These requirements and principles help player to maintain body balance and the rational utilization of technology. Therefore, it make the application of technical action be reasonable to master the single technical actions. In the basketball competition, most of the players' offensive technical actions appear in the form of combined technology. The connection between two or more actions should be consistent with each other. The previous action should be ready for the next action to create favorable conditions, which makes the transition to the next action be smooth. In order to implement this goal, the basketball player must control his or her body's center of gravity and balance whether he or her holds the basketball or not. The body balance is the premise and guarantee of the usage of combination technology. Merely mastering the standardized single technical actions and coherent combination technology, the basketball player can execute the attack technology fast, accurately and reasonably.

Observation is a prerequisite for basketball players to reasonably use and adapt techniques in the competition. It runs through every single technical action during the whole competition (Polzien et al. 2019; Savaki et al. 2021). From the perspective of exercise physiology, the balance of human body refers to adjust the tension of skeletal muscle or produce corresponding movement through the central nervous system to maintain or correct the posture of the body. By observing the incoming stimulation under the regulation of brainstem, basal ganglia, cerebellum and cerebral cortex, the basketball player feels the linear acceleration movement, rotational acceleration movement and the change of muscle tension in space to maintain body balance. Observation should be extensive and focused. According to the specific observed conditions, the basketball player can conduct comprehensive analysis to make instantly correct judgment and take positive, effective, independent or cooperative countermeasures and actions. In a fierce competition, the observation and judgment ability is helpful to maintain body balance and competitive level. It reflects the athletes' adaptability, basketball consciousness and on-the-spot experience.

In modern basketball competition, players are in fierce confrontation whether they have the ball or not. Confrontation has become one of the main characteristics of modern basketball, which is mainly reflected in the competition for time and space. In order to maintain a good physical balance in confrontation, take the initiative and give better play to the technical level, the players must have the awareness of confrontation, establish the confidence of confrontation, dare to do actions and actively contact. The players should have good physical quality. The acceleration of attack or defense speed and the improvement of confrontation ability in modern basketball require athletes not only to be agile, but also to have good endurance quality and strength quality. With good endurance, the players can always maintain abundant energy and vigorous fighting spirit during the competition. With good strength quality, the players cannot only withstand the interference of collision, but also maintain good body balance in the fierce competition to ensure the stability and consistency of technical movements.

The confrontation between attacker and defender in modern basketball competition is not only the confrontation of strength, but also a psychological contest (Xiao 2020; Guahui & Jun 2018). In some high level competitions, psychological factors often play a decisive role. In the basketball sport, the main psychological qualities include will mental strength and emotional stability. The mental strength is the psychological process of consciously controlling and regulating action to achieve the predetermined purpose through difficulties. It is characterized by decisiveness and firmness. Emotional stability means that emotion must be moderate. Too high or too low emotion will make the situation be passive. Maintaining psychological stability is an important condition for grasping the rhythm of technical movements. Once athletes lose the control of their psychology in the competition, their attach will be blind attack and they will be eager for success. The associated actions become rigid and uncoordinated, which will induce the decline of the ability to maintain physical balance. The players may fail to play normally. The practice of basketball competition tells us that the psychological state of athletes is complex and rapidly changes with the stimulation of internal and external conditions. Psychological factors directly affect the ability of body balance and the application effect of technical movements. Therefore, athletes are required to have excellent willpower and keep calm in thought and spirit.

All the actions on the basketball court are related to footwork and body balance. Every offensive technique and cooperation must be coordinated with the help of foot movement. A good balance is needed in both quick escape and cut in. The players should keep static balance before moving, that is, the position of the head is vertically above the midpoint of the support surface, the center of gravity drops and falls between the feet, and the upper body leans forward slightly to keep the body at an appropriate stable angle. At the moment of movement, the players should make the center of gravity of the body quickly exceed the supporting surface. In case of emergency stop, the center of gravity shall be controlled within the support surface to facilitate the connection of the next attack action.

Getting the ball refers to catch the ball after getting rid of it. Players must catch the ball before shooting in the competition. As a good pitcher, the player must have good catching skills. Before receiving the ball, the player should drop the center of gravity, hold or squeeze your opponent with your legs, back or side of your body to maintain static balance.

Propulsion and transfer refer to the process of controlling the ball between players from the back court to the front court. It is a combination of dribbling, passing and receiving. Before propulsion, The body should maintain static balance. In the propulsion moment, the player should make the body quickly out of balance. In the process of promotion and transfer, the player must maintain the body's steady-state balance.

The breakthrough technique of holding the ball is an aggressive offensive technique in which the player holds the ball quickly to surpass their opponents by using footwork and dribbling techniques.

The timing of breakthrough and the choice of route are certainly important. However, the preparation posture before breakthrough and the control of balance in breakthrough also directly affect the technical effect. Before breakthrough, the player maintains a static balance posture to ensure the mobility of moving forward quickly. During breakthrough time, the back sole of the foot should be fully pushed back and up. The player must move the center of gravity forward quickly.

In the basketball competition, the rebounding is one of the important sources of gaining control. Grabbing offensive rebounds usually adopts the method of cross step to get rid of the previous two foot take-off and one foot take-off. In order to monitor and identify the balance status during basketball competition, this paper establishes a system by using acceleration sensors (Ma et al. 2018) and machine learning (Tian et al. 2020; Zhu et al. 2022). First, the acceleration signals of basketball players are collected from acceleration sensors. Then, the acceleration signals are converted as sequence of characteristic segments. The observed sequence of characteristic segments are used to learn a machine learning model, such as hidden Markov model (Du et al. 2020). The learnt machine learning model is used to predict future balance status.

The main contributions include: first, a framework for basketball imbalance action monitoring is proposed; second, the hidden Markov is introduced to depict the state sequence during basketball playing; lastly; the proposed imbalance detection framework is evaluated on a private dataset to show its effectiveness.

The remains of this paper is organized as follows: the framework for balance monitoring by using multi-sensors for basketball sports is proposed in Section 2; the experiments and simulations are provided in Section 3; Section 4 is the conclusion and discussions.

2. BALANCE MONITORING AND DETECTION BY USING MULTI SENSORS FOR BASKETBALL SPORTS

The balance monitoring can be implemented through the acceleration signals of human motion which are collected by acceleration sensors. In general, the acceleration signal is a kind of random signals which are complex to describe. It is unrealistic to analyze the acceleration signal to summarize the associated characteristics and obtain a fixed function form as the mathematical expression.

In the process of sports, there are different movement states which transfer in turn. The movement behavior is composed of a series of different states. This paper adopts movement state transition to establish a mathematical model for explaining the movement behavior. The movement states are collected by wearable human motion monitoring system. First, the acceleration signals are used to summarize the regularity of the imbalance states. The imbalance state is the change or transfer of a series of motion states. The acceleration signal of imbalance state is the performance of the changes of different motion states in time series.

The Hidden Markov is a statistical model, which describes the random process to characterize and identify the time series data. This paper adopts the athlete's action monitoring system to collect human acceleration signal during basketball playing and analyze the variation law of human acceleration in the process of imbalance state. The imbalance state is divided into different sub-stages according to the acceleration signal. Meanwhile, the paper designs an observation sequence extraction method to summarize the characteristic segments of acceleration signal. The observation time sequence of the imbalance state is used to train the hidden Markov model. After the model training of the fall process is completed, this paper designs a fall detection algorithm based on the hidden Markov model. The acceleration signal is used as the input data, and the matching degree between the observation sequence of the characteristic segments of the acceleration signal and the hidden Markov model is used to predict the imbalance state. Then, the imbalance state detection is converted as a hidden Markov model evaluation problem.

When using hidden Markov model for constructing time series data model, there are two problems to be solved. First, it requires to define the movement state and the transfer order between different movement stages. Second, the original acceleration signal should be represented as the features that can reflect the transition of different stages. These two issues are solved by using time series analysis method. The time series analysis refers to statistically analyze and summarize the regularity essence from irregular surface phenomena. This paper adopts time series analysis to design an acceleration observation sequence extraction method.

From the point of view of signal processing, the acceleration signal is not continuous. It is a discrete signal, which is determined by the sampling frequency. In the time domain, the acceleration signal is a discrete time series which can characterize the human motion behavior in a period of time. In order to study the acceleration change over a period of time, this paper designs a movable signal processing window, termed as time window. The signal over a period of time can be intercepted, and then the observation sequence of the signal over that period in the time window can be extracted to study its change characteristics. If the whole section of signal is analyzed, only the time window needs to be continuously moved by a certain step. The time window can improve the efficiency of signal analysis and make the analysis be flexible.

In order to train the hidden Markov model for imbalance state detection, it first collect the acceleration observation sequence of the basketball action. The signal intercepted by the time window is the sampling data of the imbalance state. The initial parameters of hidden Markov model is set as $\lambda = \left(M, N, \pi, A, B\right)$.

The parameter M represents the number of hidden states in HMM. The hidden states in HMM include equilibrium state, imbalance state and collision state. Then, the hidden state set is represented as $S = \{s_1, s_2, s_3\}$.

The parameter N represents the number of observation sequences, which is the same as the number of eigenvalues of the observation sequence. The eigenvalues correspond to the observation variables. The observation variable set is represented as $V = \{v_1, v_2, v_3, v_4, v_5\}$.

The parameter A represents the probability distribution of state transition. The parameter B represents the probability distribution of observation sequence. The parameter π represents the initial state probability distribution, which is written as follows:

$$\pi = \left\{\pi_i, 1 \le i \le 3\right\}, \quad \pi_i = \frac{1}{3}, \quad i = 1, \ldots, 3 \tag{1}$$

Figure 1 shows the transition of the parameters in HMM.

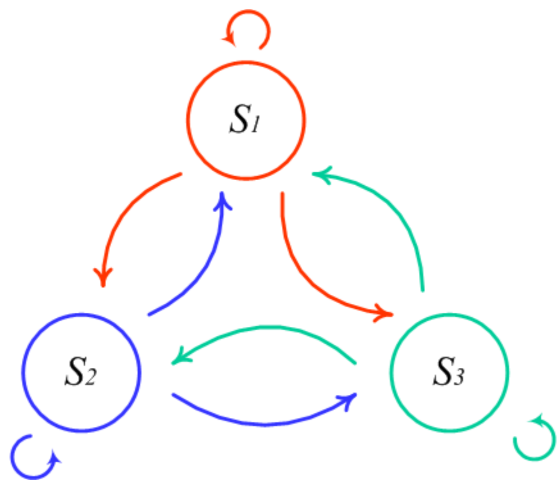
In Figure 1, S_1, S_2 and S_3 are three states; the arrows represent the direction of state change. The HMM model can be learnt through Baum-Welch algorithm which is described as follows:

Step 1: Let $\{O_i\}$ be the imbalance state observation sequence and λ be the initial model parameters. It computes the forward variable $\alpha_t(i)$ and backward variable $\beta_t(i)$. Here, the forward variable represents the probability of observation sequence $\{O_i\}$ with λ at the moment t. The forward variable is represented as follows:

$$\alpha_i\left(i\right) = P\left(O_1, O_2, \ldots, q_t = s_i \middle| \lambda\right) \tag{2}$$

The backward variable represents the probability of the observation sequence of action state s_i with parameter status λ at moment t. The backward variable is represented as follows:

Figure 1.
The illustration of state transition in hidden Markov model



$$\beta_i\left(i\right) = P\left(O_1, O_2, \ldots, \middle| q_t = s_i, \lambda\right) \tag{3}$$

By using forward and backward variables of model λ for observation variable $\{O_i\}$, we can obtain the output probability $P\left(O\middle|\lambda\right)$ which represents the matching degree between the observation sequence and the model. The output probability is computed by the following equation:

$$\begin{aligned} P\left(O\middle|\lambda\right) &= \sum_i \alpha_t\left(i\right)\beta_t\left(t\right) \\ &= \sum_i \sum_j \alpha_t\left(i\right) a_{ij} b_j\left(O_{t+1}\right)\alpha_{t+1}\left(j\right) \\ &= \sum_i \alpha_L\left(i\right) \end{aligned} \tag{4}$$

In the Equation (4), L represent the length of observation sequence.

Step 2: By combining the forward and backward variables, we can compute the probability $\gamma_t(i, j)$ of which the action state s_j at moment $t+1$ is from action state s_i at moment t. The probability is represented as following equation:

$$\begin{aligned} \gamma_t\left(i, j\right) &= P\left(q_t = s_i, q_{t+1} = s_j \middle| O, \lambda\right) \\ &= \frac{\alpha_t\left(i\right) a_{ij} b_j\left(O_{t+1}\right)\beta_{t+1}\left(j\right)}{P\left(O\middle|\lambda\right)} \end{aligned} \tag{5}$$

The probability that the observation sequence $\{O_i\}$ is under action state s_i at moment t is represented as following equation:

$$\delta_t(i) = P\left(q_t = s_i \middle| O,\lambda\right) = \frac{\alpha_t(i)\beta_t(j)}{P\left(O\middle|\lambda\right)} \tag{6}$$

Step 3: We utilize HMM model to iterative update Equation (7) and (8). The results of Equation (7) and (8) are temporarily stored:

$$\bar{\pi}_i = \delta_t(i) \tag{7}$$

$$\bar{a}_{ij} = \frac{\sum_t \gamma_t(i,j)}{\sum_t \delta_t(i)}, \quad \bar{b}_{ij} = \frac{\sum_{t,O_k=v_k} \delta_t(j)}{\sum_t \delta_t(j)} \tag{8}$$

Step 4: Repeat Step 1 to Step 3 until it traverses the whole training set to reach the optimal solution.

The imbalance detection method based on HMM model can identify whether the basketball player is under imbalance state. The flowchart of imbalance detection is illustrated in Figure 2.

The flowchart in Figure 2 contains four steps. First, it set a sliding window in acceleration signal. Second, the sliding window is used to extract acceleration observation sequence. Third, the observation sequence data is input into HMM model to obtain the probability $P\left(O\middle|\lambda\right)$ according to Equation (2), (3) and (4). The probability indicates the matching degree between observation sequence and imbalance state. Lastly, it compares output probability $P\left(O\middle|\lambda\right)$ and threshold P_{th}. When $P(O|\lambda) > P_{th}$, the observation sequence is under imbalance state; otherwise, it is not.

3. EXPERIMENTS AND SIMULATIONS

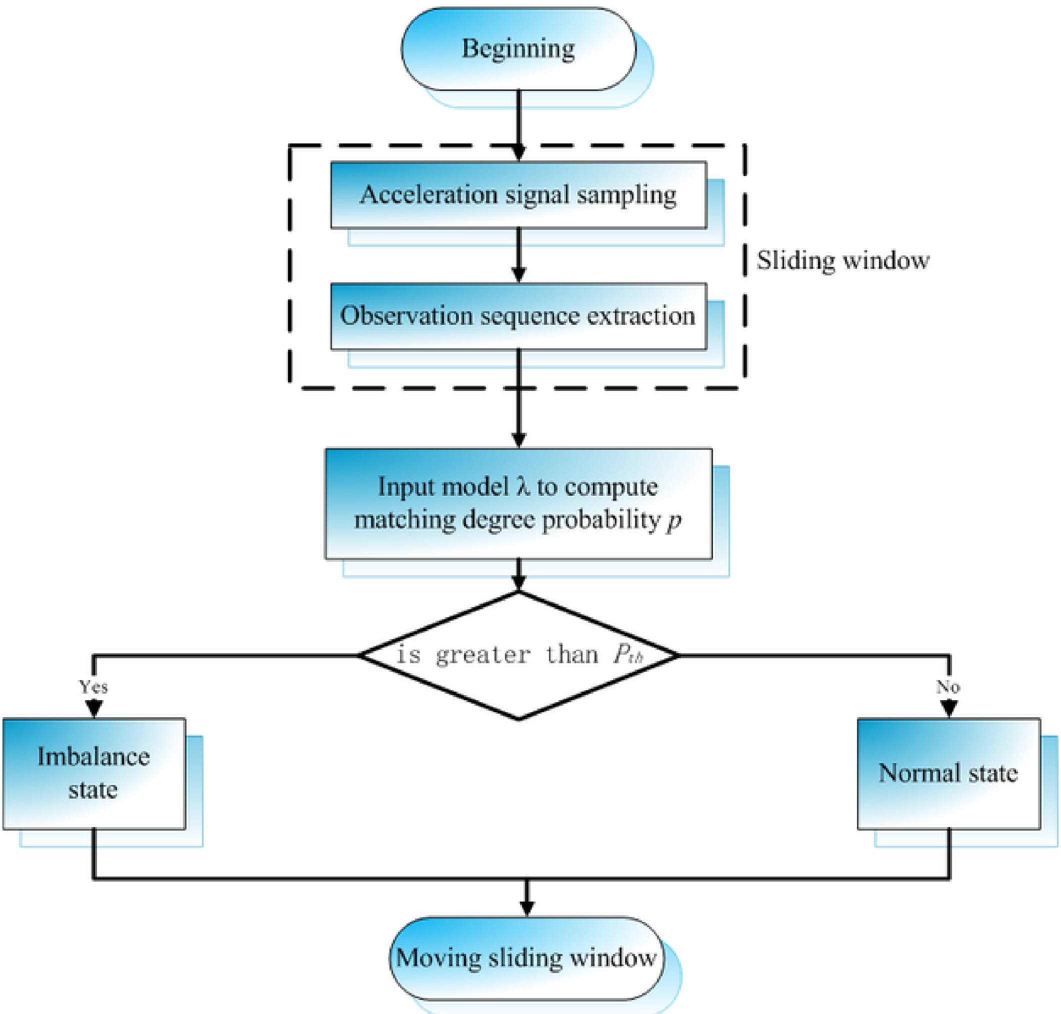
In this section, we will adopt the proposed imbalance state detection method in daily university basketball players training. The acceleration signals are collected by acceleration sensors. The acceleration signals are collected from 60 basketball players in daily competition and training. Each basketball player repeats getting the ball, propulsion and transfer, breakthrough, shooting, and grabbing offensive rebound. Each action is repeated 20 times. Thus, there are 6,000 samples in total, in which 3,247 actions are under normal state and 1,753 actions are under imbalance state.

The cross validation is a validation method to evaluate whether the results of a statistical analysis can be extended to an independent data set. It can eliminate the randomness when splitting the dataset as training set and test set. The principle of cross validation test is to analyze on one subset first, while other subsets are used for subsequent confirmation and verification of this analysis. In this experiment, 10-fold cross validation is adopted in this paper. The acceleration signal dataset is randomly split as ten subsets. One is used as the validation set, while the other 9 subsets are used as the training set. The procedure is repeated 10 times and ten models are learnt. The experimental results are reported as the mean of results of ten models. The cross validation can avoid overfitting learning and under fitting learning.

The precision, recall and F1-measure are used as the measurements to evaluate the effect of the imbalance state detection method. The precision, recall, and F1-measure are defined as Equation (9), (10), and (11), respectively:

$$Precision = \frac{TP}{TP + FP} \tag{9}$$

Figure 2.
The architecture of imbalance detection by using HMM model



$$Recall = \frac{TP}{TP + FN} \quad (10)$$

$$F_1 = \frac{2Precision * Recall}{Precision + Recall} \quad (11)$$

In the Equation (9), (10), and (11), the TP represents the number of imbalance states that are correctly detected; the TN represents the number of normal states that are detected as imbalance states; the FP represents the number of normal states that are correctly detected as normal states; and the FN represents the number of normal states that are detected as imbalance states. The experimental results are reported in Table 1 and Table 2.

From the results in Table 1 and Table 2, it can be found that, for proposed framework, the getting the ball achieves 97.23%, 97.36%, and 0.964 for precision, recall, and F1-measure, respectively; the propulsion & transfer achieves 96.92%, 97.04%, 0.971 for precision, recall, and F1-measure, respectively; the breakthrough achieves 95.73%, 96.14%, and 0.962 for precision, recall, and F1-

Table 1.
The performance of proposed imbalance state detection for basketball players merely using acceleration signals

Action	Precision (%)	Recall (%)	F1-measure
getting the ball	77.97	88.57	0.92
propulsion & transfer	86.78	86.97	0.58
breakthrough	62.78	91.05	0.81
shooting	76.91	64.89	0.92
grabbing offensive rebound	75.24	75.24	0.95
Average	75.94	81.34	0.84

Table 2.
The performance of proposed imbalance state detection for basketball players using acceleration signal plus observation sequence

Action	Precision (%)	Recall (%)	F1-measure
getting the ball	97.23	97.36	0.964
propulsion & transfer	96.92	97.04	0.971
breakthrough	95.73	96.14	0.962
shooting	97.54	97.29	0.953
grabbing offensive rebound	97.38	97.81	0.982
Average	96.96	97.13	0.966

measure, respectively; the shooting achieves 97.54%, 97.29%, and 0.953 for precision, recall, and F1-measure, respectively; the grabbing offensive rebound achieves 97.38%, 97.81%, and 0.982 for precision, recall, and F1-measure, respectively. The average result reaches 96.96%, 97.13%, and 0.966 for precision, recall and F1-measure, respectively. All the results of Table 2 is much better than that of Table 1. The proposed framework is much better than merely using acceleration signals.

4. CONCLUSION

In order to help basketball player training and improve their level of competitive competition, this paper establishes a framework for basketball player action detection and imbalance status monitoring. An auxiliary training system can be designed based on proposed system for basketball players in the future. In the framework, first, acceleration signals are collected by acceleration sensors to depict the basketball player's actions; second, the hidden Markov model is used to describe the change or transfer of different states during player's actions; third, the acceleration signal and observation sequence from hidden Markov are used to determine whether the player is under imbalance state. The experiments performed on a private dataset show its effectiveness. Furthermore, we will further try other signals for basketball player's training auxiliary system, such as photoelectric pulse wave, skeleton through Kinect camera and EMG signal.

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