Article

Hand Kinematics in Badminton Based on Smart Glove and Visualization Technology

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Abstract: Hand movements are typical human body fine movements, which can help people accomplish complex jobs like grab objects and operate tools. It is mainly characterized by the flex and pressure applied by its fingers. In a badminton game, dexterity hand movements are essential for the player to conduct extraordinary skills. As a result, such game is chosen to analyze typical hand kinematics. However, only rely on bare eye observation cannot recognize and record such movements. Thus, a more accurate smart glove with sensing functions for finger pressure and flex is employed in this case to measure the finger bending and force situation during the forehand grip and backhand grip. An athlete and an amateur are chosen to conduct the grip movement in the static states, and the data is recorded by the smart glove. The measured parameters are then visualized to analyze different grip movement, which can provide a reference for the badminton learners to perform a correct technical movement.

Keywords: badminton; hand fine movement; smart detection; visualization analysis

1. Introduction

Hand movement for a specific task is conducted by small muscle groups on fingers and palms, and the proficient control of such movements is the most important ability for human beings. The most typical actions of this motion is characterized by the movement of fingers and wrists, which are mainly reflected in the pressure and flex angle changes, for example, in badminton, table tennis, tennis or daily grasping operations. Thus, measurement and visualization of the grasping operations can help people precisely determine the human hand kinematics.

Badminton is one of the most popular sports around the world [1], which can enhance both the physical and the spiritual function of the human body. One factor that determine the success of a badminton game is the racket grip for different types of movement, such as forehand/backhand smashes, short drops, and long clears [2]. A correct grip type can increase the power and accuracy of the stroke and result in optimal performance. However, using only the wrist to control the badminton racket does not allow very many grip variations. The badminton grip variation of the racket is mainly controlled finely through the fingers. Fine finger control of the badminton grip is dependent on not only the grip posture, but also the grip strength of the fingers [3]. Therefore, to measure and visualize the badminton grip types can help the players and coaches precisely to evaluate the hand kinematics in different strokes and improve the training efficiency.

In recent years, most of the fine motion measurement has been conducted based on high-speed cameras [4] or wearable sensors [5] like flex sensors or accelerators. The camera-based system can obtain the joint angles and angular velocities from pre-recorded videos. MS Salim et al. [6] adopted four Oqus cameras to detect the arm trajectory and acceleration to analyze the motion difference between male and female players. A markerless motion capture system was developed by Cheryl D. Metcalf et al. for measurement of hand kinematics by using a commercially available gaming system (Microsoft Kinect) [7]. However, the camera-based systems are easily affected by light conditions, and their resolution is inadequate to capture the fine motion of the fingers. To avoid the demerits of the camera-based system, the wearable devices have been proposed in many researches. Chew Zhen Shan et al. [8] established a so-called Opal sensor to monitor the acceleration and angular velocity of the upper limb during the smashing movement. Alvin Jacob et al. [9,10] developed a mobile measuring device for capturing human finger movement by using five flex sensors. Although the above-mentioned wearable sensors could record hand kinematics accurately, such as acceleration or angular velocity, they were not able to detect the grip strength of the fingers in different strokes. In addition, the visualization of the grasping operations was not mentioned in badminton, which makes it hard to understand the grip posture and grip strength from the abstract data acquired by the fine motion measurement systems.

Not only the grip posture but also the grip strength can affect the velocity or the route of the shuttle. Therefore, exploiting a detection system with comprehensive analysis ability for both grip posture and grip strength is crucial and necessary. To solve the problems, this paper proposes a smart glove with the sensor array of flex sensors and pressure sensors based on the kinetic and anatomy principles of human hands. On the other hand, to visualize the grip posture and grip strength of a badminton grip type, a hand movement visualization system based on Unity and ANSYS is proposed. Finally, to verify the feasibility of the measurement and visualization approaches, two typical badminton grip types are studied in this paper.

2. Methodology

Conducting the analysis for the complex and unpredictable hand movement requires a well-established system based on state of art technologies. As shown in Figure 1, the overall system in this paper is divided in three sections: the data collection module based on the flex and pressure sensors, the data processing module based on the Arduino platform, and the visualization module based on the Unity and ANSYS software.

2.1 Smart glove based on flex sensors and pressure sensors

The main fine movement characteristics of the human hand are the finger joint angles as well as the pressure generated by fingers and the palm.

To capture the hand kinematics of finger joint angles as well as the pressure generated by fingers and the palm, flex sensors [11] and pressure sensors [12] are employed to construct a smart glove system. As shown in Figure 2, twenty-one pressure sensors [13] and ten flex sensors [14] are deployed at different positions on the smart glove. According to the anatomy principle, the

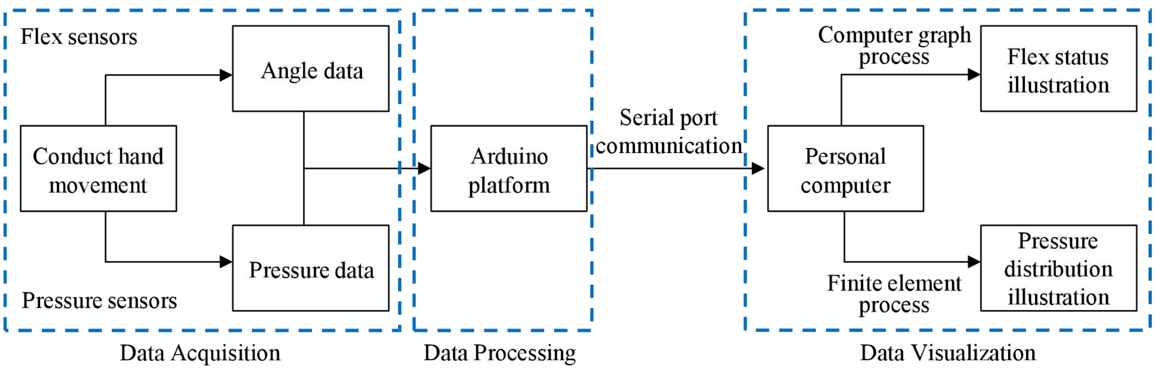


Figure 1. The flow chart for the whole system.

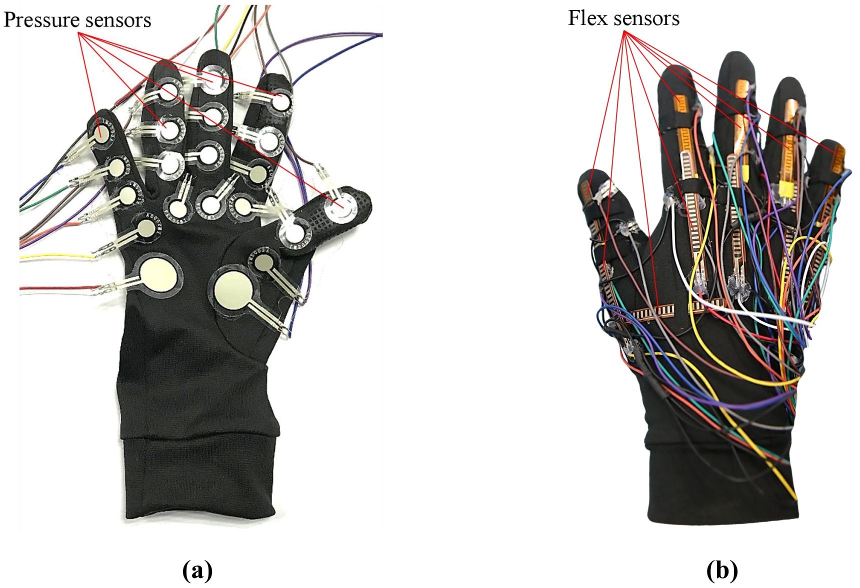


Figure 2. The overview of the smart glove: (a) front view; (b) back view.

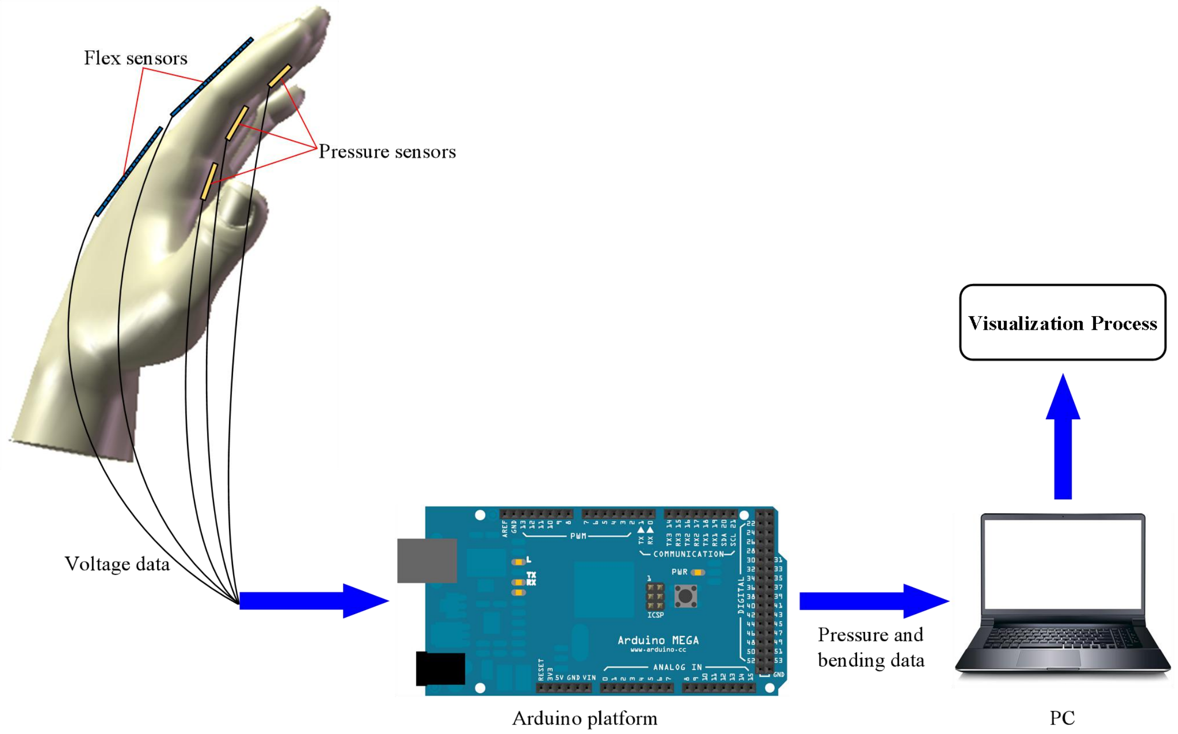


Figure 3. The working principle of the smart glove.

interphalangeal and metacarpophalangeal joints of each finger are the main generation points during hand movement. Thus, pressure sensors are installed at these points to accurately detect the pressure distribution of the human hand. Due to the less contribution of the distal interphalangeal joint during the grip movement, this paper only employs one flex sensor for the upper two joints.

Figure 3 shows the working principle of the smart glove. The information of the finger joint angles as well as the pressure acquired by the glove is stored and analyzed in the Arduino system. All the data will be then transmitted to the PC through the 2.4G communication equipment installed on the Arduino board. Visualization will be processed based on the data of the finger joint angles and pressure.

2.2 Visualization system

Since the human hand conducts multi-dimensional and complex movement, the parameters displayed only by data table may confuse researchers. Thus, the Unity and ANSYS tools are employed for the data visualization of hand movement.

Unity [15] is a tool for establishing computer graph (CG), which can conveniently illustrate the flex status that are extracted by bar type sensors located at the back of human hand. This paper adopted the RotateAround command in C# to rotate the finger segments around the joint to the desired angle.

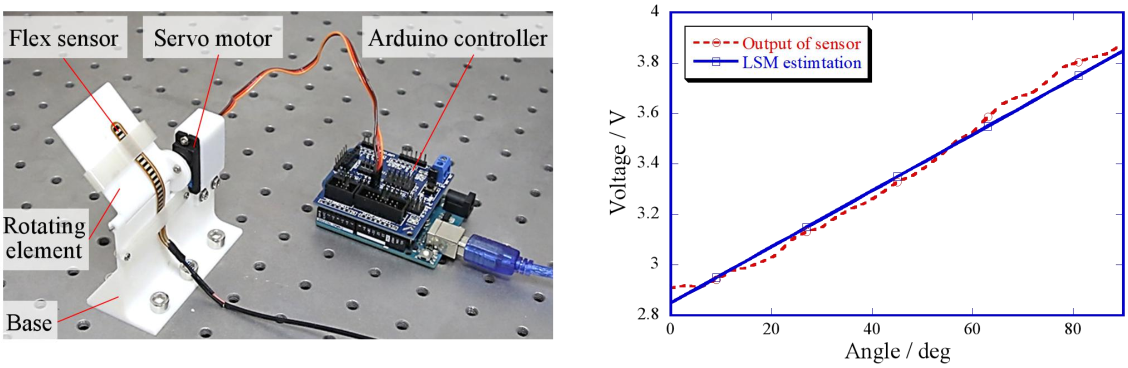
ANSYS [16] is a finite element simulation software that can reveal the complex object responses under certain external conditions. Since the data of pressure distribution are accessed by circular sensors installed on the human hand, the illustration can be displayed by exerting the detected value on the corresponding area successively, where the hand model is stabled by a fixed support during the simulation.

3. Experiments

3.1 Sensor calibration

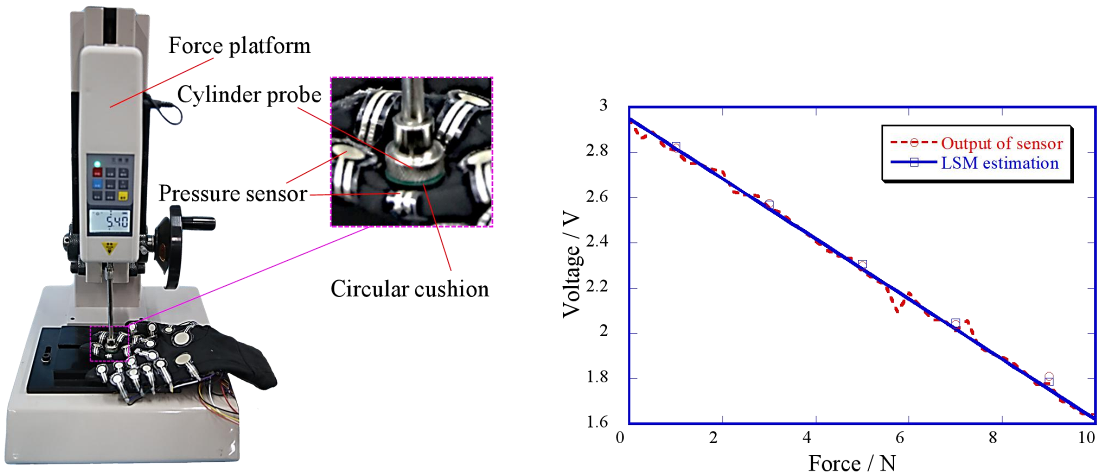
The primary step is to calibrate the flex sensors and pressure sensors installed on the smart glove, which can clarify the relationship between the voltage acquired by the Arduino platform and the actual bending angles or pressure bear by human fingers.

The calibration experimental setup for the flex sensor is shown in Figure 4(a). A rotating



(a) **(b)**

Figure 4. The calibration for the flex sensor: (a) experimental setup; (b) calibration result.



(a) **(b)**

Figure 5. The calibration procedure for the pressure sensor: (a) experimental setup; (b) calibration result.

element is driven from 0° to 90° by a servo motor, and the actual angle can be obtained from the servo motor by an Arduino controller. Also, the output voltage of the flex sensor is recorded by the Arduino controller to compare with the actual angle. The calibration result is shown in Figure 4(b), and the characteristic function is fitted by the least square method (LSM).

The calibration experimental setup for the pressure sensor is shown in Figure 5(a). A force platform (HP-50, HANDPI, CHINA) is used to apply pressure to the pressure sensors. A circular cushion is attached to the head of the force platform for ensuring that the pressures are applied with in the validated rage. As shown in Figure 5(b), the pressure sensors are tuned by applying several forces between 0 N and 10 N, and their characteristic functions are obtained via LSM as well.

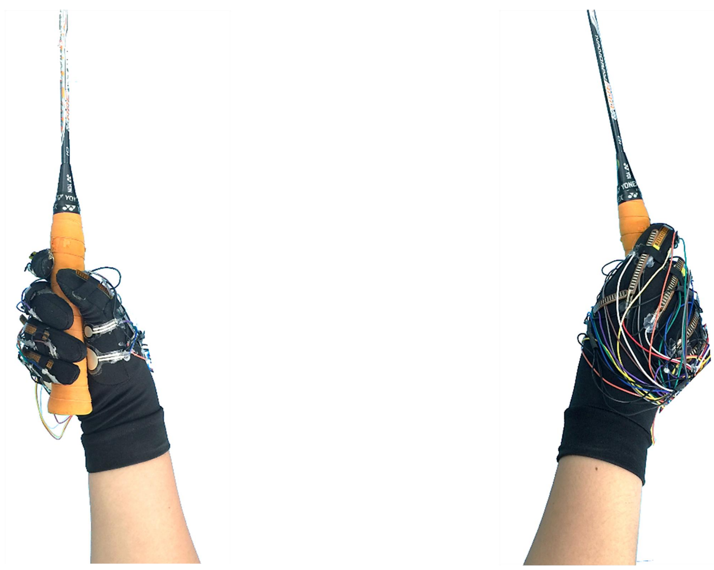
3.2 Measurement of hand kinematics

A correct badminton grip is the foundation of playing badminton. Gripping the racket wrongly will decrease your stroke's accuracy and power. A good grip on badminton rackets can reduce injuries, increase the accuracy of shots and produces more efficient hits. The basic grip types of badminton can be generally divided into forehand grip and backhand grip. Therefore, the two grip types are studied in the experiment stage to illustrate the difference between professionals and amateurs.

The measurement and visualization of the grip type is conducted based on the data obtained through the flex sensors and pressure sensors of the smart glove. The test procedure is accomplished by a professional badminton athlete and a badminton amateur. Each movement is conducted for 15 times and the average value of them is taken as the result.

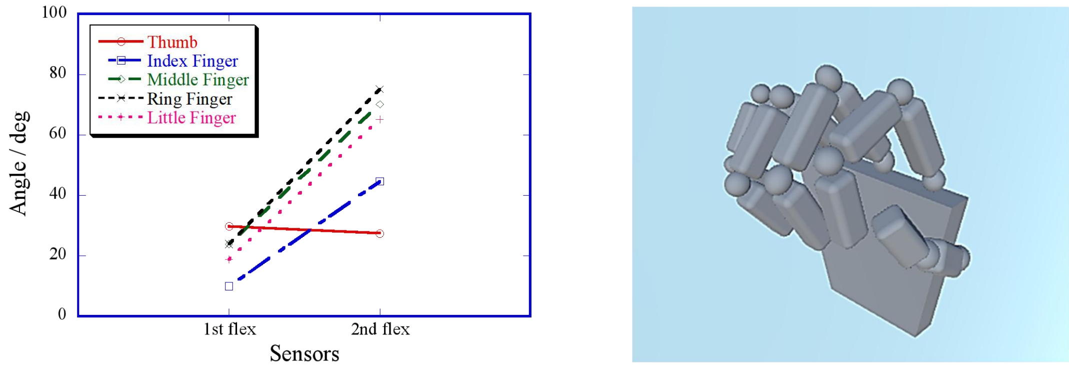
4. Results and discussion

The forehand grip is used to hit shots that are on the forehand side of your body and around the head shots. The badminton racket handle has two wide parts that are in line with face of the racket. The index finger should be pressed over one of the wider surfaces and the bottom 3 fingers hold the racket handle. The thumb can be adjusted comfortably anywhere near the wider surfaces to create a V-shape between the thumb and the index finger, which enable the players to switch grip quickly. It should be noted that the index finger should be the one "in control" in a forehand stroke. It means the index finger is used to push the racket forward when doing a forehand stroke.



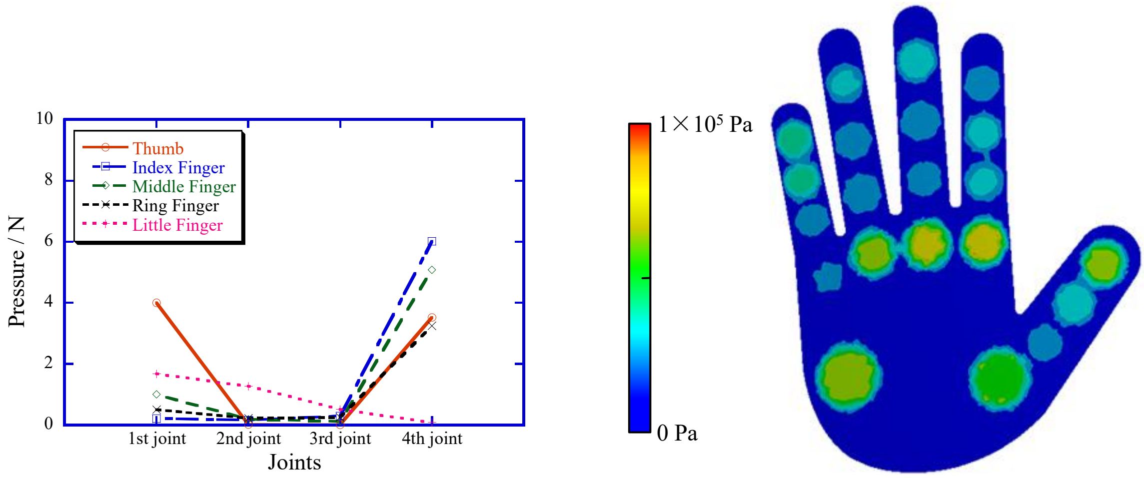
(a) **(b)**

Figure 6. Forehand grip of a professional athlete: (a) front view; (b) back view.



(a) **(b)**

Figure 7. The flex status for the forehand grip of the professional athlete : (a) numerical detail; (b) 3D illustration.



(a) **(b)**

Figure 8. The pressure distribution for the forehand grip of the professional athlete: (a) numerical detail; (b) 2D illustration.

The backhand grip is used for all shots on your backhand side which is just the opposite side to your forehand side. While playing a backhand shot, the thumb should be placed on one of the wider surfaces of the handle and the index finger should be relaxed and moved closer to the middle finger. The backhand grip resembles a ‘thumbs up’ action, and the power of a backhand shot comes from the push of the thumb.

The forehand grip is studied in the first place, where Figures 6-8 illustrate the detail of a professional grip type and Figures 9-11 show the amateur one. Figures 6 and 9 show the grip posture of the athlete and the amateur, respectively.

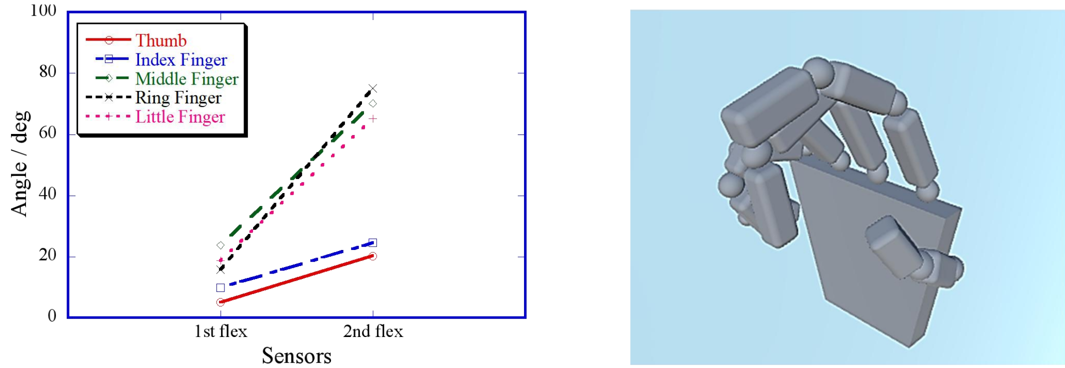
As shown in Figure 7, for the flex characteristics, the orderly arranged 4 fingers can fix the purlicue of the athlete and the racket face be on the same direction. Yet the disorderly distributed fingers of the amateur in Figure 10 deviate the purlicue from the racket face, which may decrease the accuracy and power of the shot.

From Figure 8(b), it can be seen that the main power generation points of professional players in the forehand grip are the root of each finger and the edges of the palm, where other parts of the hand play subordinate roles. By contrast, in Figure 11(b), it can be observed that the pressure on the hand of an amateur concentrate towards the medium part of the thumb, the edge of the palm, and the fingertips of the left three fingers. The pressure on the thumb of the amateur will delay the control effect for the racket orientation, and the lack of force on the metacarpophalangeal joints of the index and ring finger will curtail the strength of the shuttle.

The flowing experiment is about the backhand grip, and the illustrations are shown in Figures 12-17. Figures 12 and 15 show the grip posture of the athlete and the amateur, respectively.

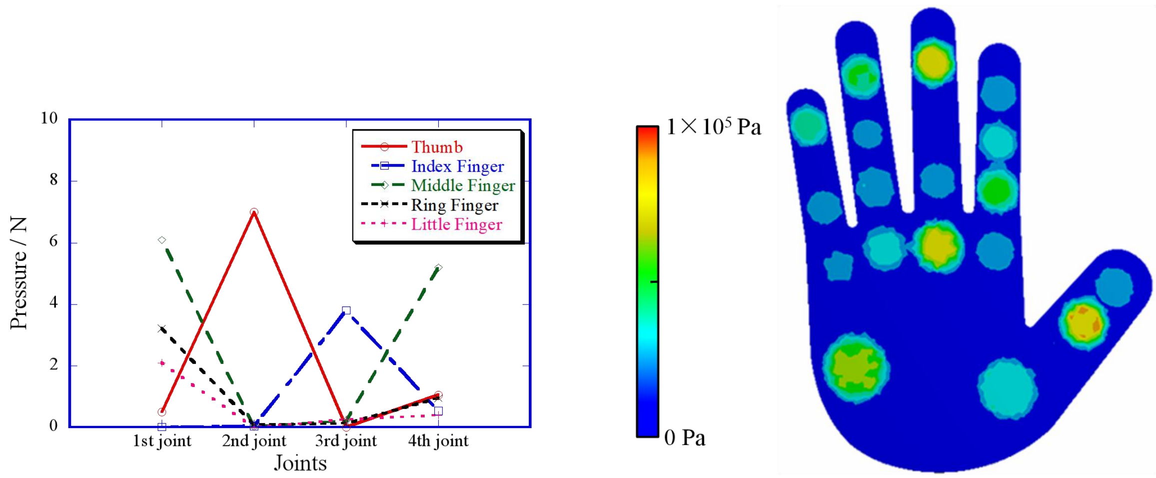
(a) **(b)**

Figure 9. Forehand grip of an amateur: (a) front view; (b) back view.



(a) **(b)**

Figure 10. The flex status for the forehand grip of the amateur: (a) numerical detail; (b) 3D illustration.



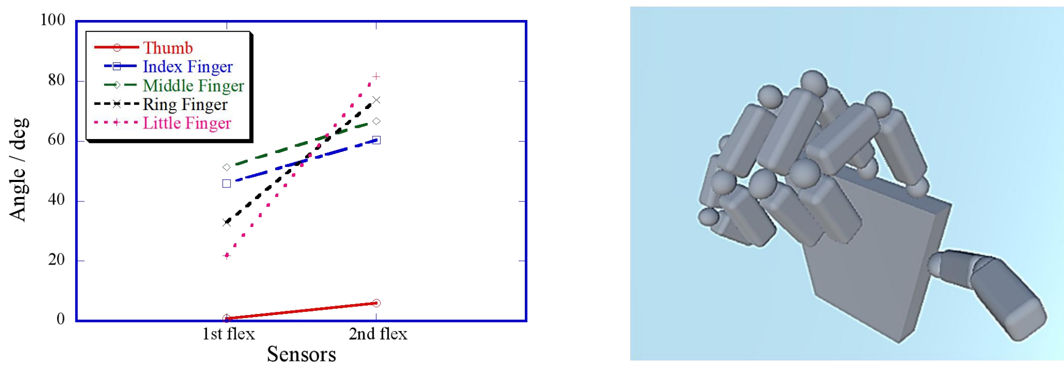
(a) **(b)**

Figure 11. The pressure distribution for the forehand grip of the amateur: (a) numerical detail; (b) 2D illustration.

As can be seen from Figures 13 and 16, the bending angle of each finger of the professional backhand grip is almost the same as the forehand grip except the thumb, which makes him easy to change the grip type during the game. However, the wrapping way of the amateur makes it unable to change the grip type rapidly.

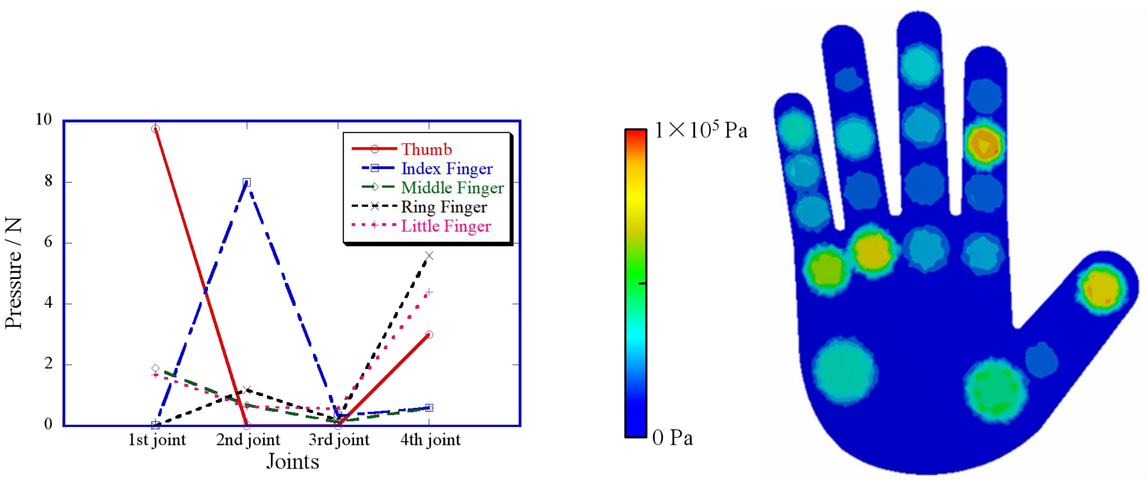
(a) **(b)**

Figure 12. Backhand grip of a professional athlete: (a) front view; (b) back view.



(a) **(b)**

Figure 13. The flex status for the backhand grip of the professional athlete : (a) numerical detail; (b) 3D illustration.



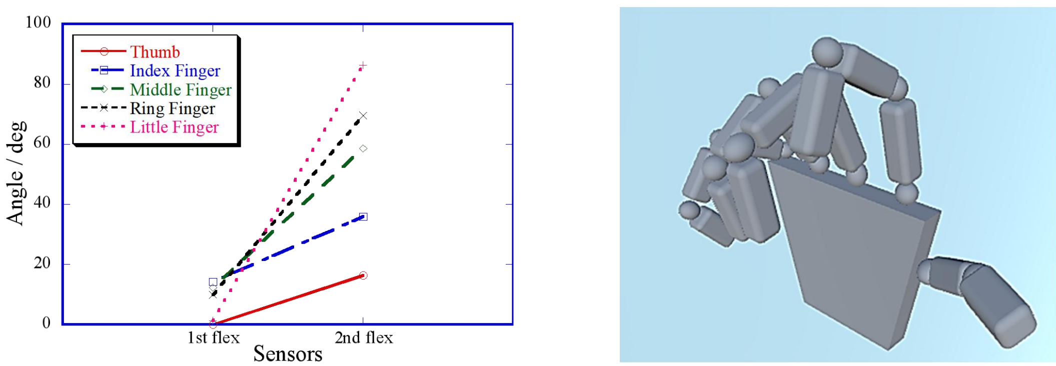
(a) **(b)**

Figure 14. The pressure distribution for the backhand grip of the professional athlete : (a) numerical detail; (b) 2D illustration.

From Figure 14(b), it can be seen the pressure distribution of the hand for the backhand grip of the professional athlete. The root of each finger, the fingertip of the thumb, and the middle section of the index finger contribute the strongest holding forces for the backhand grip in the professional movement. Differ from the skilled ones, in Figure 16(b), the amateur mainly employs his middle and top part of the middle and ring finger to hold the racket, where the four fingers tightly hold the handle and block the thumb from exerting sufficient pressure for a success hit.

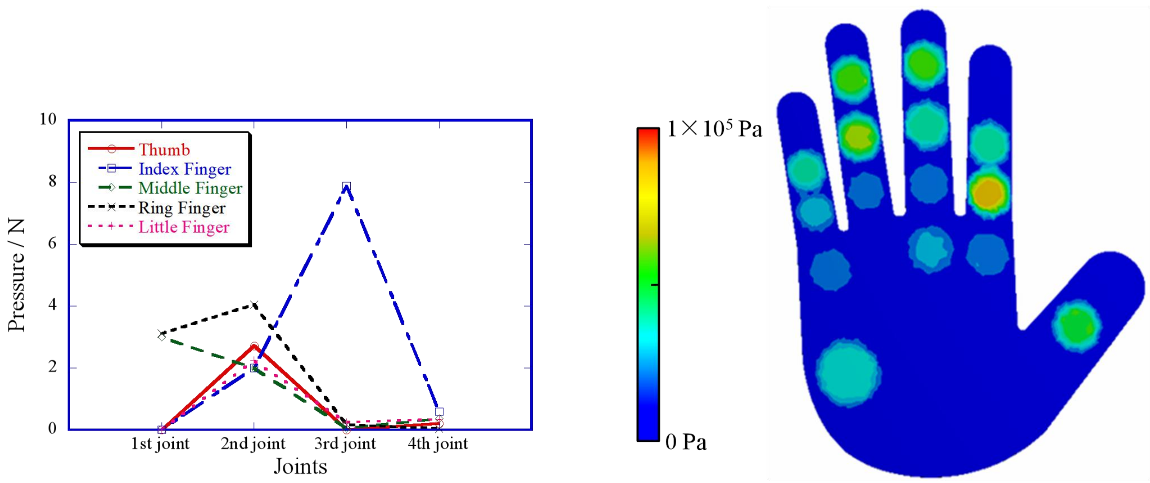
(a) **(b)**

Figure 15. Backhand grip of an amateur: (a) front view; (b) back view.



(a) **(b)**

Figure 16. The flex status for the backhand grip of the amateur: (a) numerical detail; (b) 3D illustration.



(a) **(b)**

Figure 17. The pressure distribution for the backhand grip of the amateur: (a) numerical detail; (b) 2D illustration.

5. Conclusions

In this paper, a smart glove with flex sensor array and pressure sensor array is proposed for capturing the hand kinematics. The glove is constructed by 10 flex sensors and 21 pressure sensor for measuring the joint angles and pressure of the hand. A visualization method is also proposed in this paper. The hand kinematics of two badminton grip type are investigated to verify the measurement and visualization of the smart glove. Results revealed the difference of the joint bending angles and finger pressure between an athlete and an amateur, which can provide great help for the couches and trainees in the badminton lesson.

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