

# Smart Racket Combined with Multiple Sensors

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**Abstract.** With the development of the sports industry, the demand for badminton athletes to improve their skills is increasing. Nowadays in badminton training, individuals frequently rely on coaches' instructions and draw from their previous gaming experiences to enhance their skills. However, this approach often falls short of desired outcomes. Frequently, trainers struggle to ascertain the accuracy of their shot's force, angle, or direction. At the same time, it is currently unable to monitor the physical condition of athletes in real-time without affecting their training. Therefore, it is necessary to design a racket that can assist athletes in the hitting process and monitor their physical condition. The research topic of this article is how to achieve data-driven analysis of hitting posture and monitoring of physical condition of athletes through the combination of sensors and rackets. This article combines practical production with theoretical research. It includes model making for Angle measurement parts and discusses and theorizes the parts currently impossible to achieve. Research has found that the created model can measure the angle during the hitting process, and the theory of using photoelectric sensors to measure blood oxygen concentration can also be realized. The introduction of sensors may have a significant impact on the badminton industry. In the future, the appearance of the product can be further improved to make it more practical.

**Keywords:** Biomedical engineering, badminton rackets, sensors, blood oxygen, scientific training.

## 1. Introduction

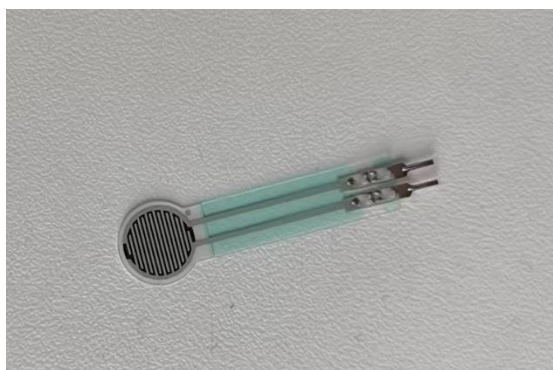
In the study Recent Progress in Flexible Pressure Sensor Arrays, the flexible pressure sensor array was introduced. It can feel pressure from different positions, while being soft and deformable [1]. The Hand-arm vibration assessment in badminton athletes during three different movements using two rackets showed a method of adding sensors to rackets to sense vibrations [2]. It provided inspiration for the research in this article. In the review of thin-film resistor sensors, the principle and development process of thin film pressure sensors was introduced [3]. The pressure sensor used in the model is a kind of thin film pressure sensor. The introduction of pulse oximetry talked about the principle of measuring blood oxygen concentration, providing a theoretical basis for using photoelectric sensors to measure blood oxygen concentration [4]. The study of piezoelectric effect introduced the piezoelectric effect, which is the working principle of piezoelectric sensors [5]. The equipment which are used includes piezoelectric sensors, and this article helps to introduce this type of sensor. In the literature review of diastolic dysfunction and atrial fibrillation in coronary heart disease surgery, the symptoms of heart fibrillation were introduced [6]. Cardiac fibrillation is one of the diseases which are plan to prevent using piezoelectric sensors, and this article will help introduce the working principle of the product. Introduction about design and fabrication of single drive tri-axis MEMS gyroscope showed the working principle of MEMS gyroscopes. The gyroscope MPU-6050 used in this product is a type of MEMS gyroscope [7]. In the study Deep Learning-based Coaching for Badminton Player Assessment, it proposed the idea of combining sensing devices and deep learning to enhance athlete skills, hoping to study athlete postures and movements and propose improvement plans [8]. This provides inspiration for the research. Research and application progress of intelligent wearable devices talked about intelligent wearable devices. They have many characteristics such as convenience, intelligence and real-time. Through wearable device detection and real-time data transmission, sensors can detect vital signs and movement information. These technologies can provide data support for people's health status, so that people can see their physical condition more intuitively [9]. Measurement of badminton racket deflection during a stroke provided some ideas for the design. It shows that the

flexibility of a badminton racket is one of the important consider factors. It can be better understood by studying the behavior of the racket during a swing. Deflection can be measured using direct methods, such as motion capture or high-speed video. Or it can be measured by indirect methods, which then need a mathematical model in order to calculate the angles. The equipment required for this method includes strain gauges and accelerometers [10].

## 2. Method

### 2.1. Determination of Grip Posture and Force of Hitting

Determination of force: In badminton skills, grip posture is one of the important factors. It is hoped to add a pressure sensor array to the grip of badminton rackets to sense the pressure at different parts. This way, the coach can know the grip posture of the athletes and the amount of force they use to hit the ball. Due to limited materials, the model used one pressure sensor instead of the pressure sensor array. The model uses RP-C10-LT, as the Figure 1 shows. This type of pressure sensor is very lightweight. The length of it is about 3cm, with a shape of thin film. It feels soft to the touch. This means that it can meeting the demand for smart racquets to hold in hand. This thin film pressure sensor is made of thin film materials, such as polyester film or silicone rubber film. These materials have good elasticity and flexibility, and can produce small deformations under compression. When the sensor is subjected to pressure, the thin film material will experience slight deformation. This can lead to changes in thin film resistance, capacitance, or other electrical characteristics. It measures pressure by detecting these changes.



**Figure 1.** RP-C10-LT

Determination of hitting angle: The angle of hitting also helps athletes analyze their movements and make improvements. The measurement of hitting angle needs the help of pressure sensor data. At the moment of hitting the ball, the pressure on the grip of the hand will suddenly increase. Therefore, by comparing the data from pressure sensors at different moments, the time of hitting the ball can be determined. Initially, 3 gyroscopes and 3 accelerometers were expected to be used. But as investigation progressed, MPU-6050 was found as a better solution. It is a MEMS sensor that integrates accelerometers and gyroscopes, as the Figure 2 shows. It is a Micro Electro-mechanical system. It helps with the measuring of acceleration and velocity of the racket, and the direction of hitting the ball, and other features. The principle of a gyroscope is that when an object is in a coordinate system moving in a straight line, if assume the system is rotating, the object will feel a vertical force and a vertical acceleration during the rotation process. People use this principle to measure direction. Then read the direction indicated by the three axis and transmit the data to the center system. In this way, MPU-6050 can get the information from 9 different axis. Therefore, the plan to measure the angle with MPU6050 is finally determined.

## 2.2. Determination of Physical Condition of Athletes

In addition, it is also hoped to monitor the physical condition of athletes, such as pulse and blood oxygen concentration, through the smart rackets. At present, a model has not been made yet, but the method has been designed.

**Determination of blood oxygen concentration:** The measurement of blood oxygen concentration relies on photoelectric sensors. A photoelectric sensor is a type of sensor that can turn light signals into electrical signals. They utilize photoelectric or photosensitive effects to achieve this conversion, which can be used to detect the intensity, position, and color of light. The blood oxygen concentration is mainly related to the binding of hemoglobin and oxygen. Hemoglobin without oxygen binding absorbs red light, while oxyhemoglobin absorbs infrared light. When using photoelectric sensors to measure blood oxygen concentration, two wavelengths of light are used: red light and infrared light. Sensors use LED lights to emit light on the skin and receive reflected light. By measuring the ratio of two types of light absorbed, the ratio of hemoglobin to oxygenated hemoglobin can be known, so the blood oxygen concentration can be determined. Due to material limitations, photoelectric sensors have not been added to the model at present.

**Determination of heart rate:** Photoelectric sensors also have the ability to measure heart rate. Every time the heart beats, the flow of blood causes the expansion and contraction of small blood vessels on the surface of the skin. The more blood there is, the stronger the ability to absorb light, so the signal received by the sensor will change. As the heart beats, this change will appear periodically. When using a photoelectric sensor to measure heart rate, the cycle of the light signal received by the sensor can be used to determine each heartbeat. So, the heart rate can be calculated based on the number of beats.

**Improvement:** Although photoelectric sensors have the ability to detect pulse, they can only distinguish periodic changes and cannot distinguish small vibrations. Some diseases, such as heart fibrillation, are along with small vibrations during the beating of the heart. This kind of vibration cannot be detected by photoelectric sensors. Therefore, sensors for measuring vibration are also necessary. The pressure sensor on the grip will be used for this purpose. As the heart beats, the contraction and relaxation of blood vessels can cause vibration to the skin. These vibrations can be sensed by piezoelectric sensors and turned into data. By analyzing the data, people can know which vibrations are normal heartbeats and which are abnormal. This can help people monitor the occurrence of several diseases. Therefore, for the determination of heart rate, pressure sensors are more suitable than photoelectric sensors, while also have the ability of monitoring certain diseases

## 2.3. Transmission of Signals

Just measuring isn't enough. The data acquired by sensors needs to be showed to athletes and coaches. Only then can improvement plans be proposed. Bluetooth module HC-05 is decided to be used for data transmission, as the Figure 2 shows. The HC-05 Bluetooth module is a commonly used Bluetooth serial port module that can convert serial port data to Bluetooth data. It gives devices the ability to communicate wirelessly through Bluetooth. HC-05 has two working modes: active and passive. In active mode, it can search for other Bluetooth devices and connect automatically. In passive mode, it can wait for other devices to connect and respond to their connection requests.

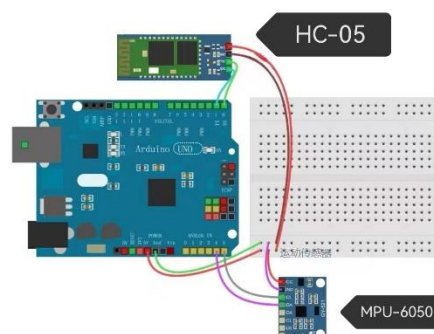


Figure 2. FC-05 and MPU-6050

### 3. Result

#### 3.1. Current Achievements

The current model is shown in Figure 3, which includes the pressure sensor, gyroscope, and Bluetooth. Once the smart racket assembly was finished, it is followed by practical testing to verify the feasibility and functionality of the solution. As an example, ten serves using the forward grip was conducted, collecting ten sets of data in the process. Subsequently, the gathered data was transmitted to a mobile phone with Bluetooth. Below, a complete set of data is showed as a sample.

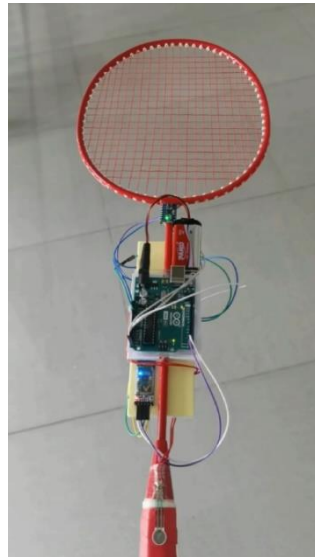


Figure 3. Current model

As shown in Figure 4, this is what athlete or coach can see on the screen of receiving device like mobile phone. The Figure shows angle of x y z, acceleration of the racket, and pressure on the handle. The acceleration is divided into value of the acceleration in three directions of x y z. In physics, the inclination angle can be used to describe the rotation or displacement of an object relative to the reference axis. And the angles in Figure 4 right shows the inclination angle in three directions. Athletes can know the time of hitting the ball according to the changes of pressure data.

```
x acceleration:-0.21
y acceleration:-1.28
z acceleration:0.28
x Angle:722.35
y Angle:972.52
z Angle:-228.54
press:0.00g

x acceleration:0.07
y acceleration:-2.00
z acceleration:-1.24
x Angle:771.92
y Angle:966.69
z Angle:-244.61
press:156.40g

x acceleration:0.39
y acceleration:-2.00
z acceleration:-2.00
x Angle:688.40
y Angle:912.23
z Angle:-286.58
press:527.86g

x acceleration:-0.70
y acceleration:-2.00
z acceleration:1.72
x Angle:606.49
y Angle:827.35
z Angle:-273.06
press:48.88g

x acceleration:1.30
y acceleration:-0.97
z acceleration:1.42
x Angle:558.19
y Angle:841.90
z Angle:-261.27
press:0.00g
```

Figure 4. Data sent to the phone by FC-05

When swinging, the racket undergoes a process of accelerating and then decelerating. Firstly, the pressure on the handle of the racket gradually increases as fingers exert force. At the same time, the athlete's arm begins to swing. At the moment of hitting the ball, the pressure should reach its maximum. The player will control the racket to slow down after the racket hitting the ball, which means that the pressure will start to decrease. According to the above analysis, the moment when pressure reach its maximum in the data will be the moment of hitting the ball. The pressures are listed in Table 1 below for data of 10 tests. The red ones are the sections which can help with finding the maximum value.

**Table 1.** Collection of pressures

Number	pressure changes during the swing (g)								
1	0	146	454	513	518	478	337	136	9.78
2	0	9	34	229	948	200	105	6	0
3	0	0	20	156	527	452	144	48	0
4	0	83	122	122	112	43	576	923	146
5	0	73	351	395	317	263	1114	288	53
6	0	195	405	586	478	992	1055	156	53
7	0	254	513	503	498	224	92	9	0
8	0	117	430	327	474	962	53	4	0
9	0	249	239	425	503	493	175	6	0
10	0	156	395	273	161	215	806	708	161

### 3.2. Future Plan and Possible Improvements

In the future, the only pressure sensor is hoped to be replaced by a pressure sensor array, which can show the pressure at every point of the grip. Photoelectric sensors are also planned to be added to measure blood oxygen concentration. In the future, there is still room for improvement in this device.

**Wearing comfort:** wearing comfort can be improved mainly in two ways: skin affinity and lightweight, which helps with better user experience. Better materials and more advanced circuit technology are the main directions of thinking. So far, most badminton rackets are made of materials such as fiber, graphite, and aluminum. These materials can already be strong and durable, but their surface may not offer optimal comfort during long-term use. In the future, incorporating carbon nanotubes or other flexible materials can be considered to enhance comfort and ensure a better fit for the player's hand. Additionally, current racket circuits often use traditional conductive materials like copper and silver, which meet conductivity requirements but may add to the overall weight of the product. In the future, people can explore the use of new conductive materials such as graphene, along with advancements in integrated circuit technology, to reduce weight and size while maintaining performance.

**Accuracy:** It is believed that accuracy can be improved in the following two aspects. First is reducing the influence of temperature. The properties of materials are often affected at different temperatures, so it is necessary to search for materials that are less affected by temperature, so that piezoelectric sensors can still be applied in more situations. In addition, change of body temperature can affect the measurement of blood oxygen. For example, during exercise, the surface temperature of a person will significantly increase. When the photoelectric sensor receives the same color of light as usual, it means different blood oxygen concentrations. So, a temperature sensing device and related calculation methods is important to ensure that the blood oxygen concentration is always accurate at different body temperature. Second is using high performance optical materials for the photoelectric sensor. More advanced and transparent optical materials can be used to enhance the transmission ability of light, and reduce scattering losses, which can improve the sensitivity of sensors.

**Cost:** For medical equipment, price is also very important. They should be as affordable as possible for most people. Production costs can be reduced by designing batch production lines or other methods.

## 4. Conclusion

This article introduces a solution of a smart badminton racket. It aimed at meeting the increasing demand in the sports industry for athletes to improve their skills and test their physical condition. Current training methods often rely on coach guidance and past game experience, but can't provide accurate feedback on hitting force, angle, and direction. To address this gap, the research designed a racket integrated with sensors to help athletes during training and monitor their physical condition in real-time. The methods section details the plan of the smart racket, including determination of grip posture and hitting force through pressure sensor, determination of angle through gyroscopes and accelerometers, and plans for monitoring athletes' physical conditions such as heart rate and blood oxygen concentration through photoelectric sensors. The results section indicates the successful integration of sensors into the smart racket, with actual testing to make sure it is feasible. Future plans involve replacing the single pressure sensor with an array, for specific grip analysis and integrating photoelectric sensors for blood oxygen concentration monitoring. Additionally, improvements in comfort and lightweight design are considered, suggesting the use of new materials to improve user experience without changing performance. Overall, the article presents a comprehensive approach to developing a smart badminton racket, combining practical implementation with theoretical insights, and outlining future directions for improvement.

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