ACTUATE Racket: Designing Intervention of User's Performance through Controlling Angle of Racket Surface

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ABSTRACT

In this study, we introduce a novel way to interact with sports players during the activities through actuating sports equipment. We propose ACTUATE Racket, a new type of sports racket that can change its angle of the surface. We made the table tennis racket prototype that has two servo motors for controlling the angle of its surface. The goal of this research is to explore the design opportunity of the relationships between user and racket by creating new interactions with the racket. We investigate practice methods of racket sports introductory activity: bouncing a ball on the racket rhythmically. We present three approaches with the racket. (1) One approach is to stabilize the angle of the surface during the activity. (2) Another approach is to amplify the angle of the surface regardless of the grip angle while user bounces the ball. (3) The other approach is to intentionally change the surface of the racket for each swing so that the user have to adjust the angle of its surface. We report the results and insights and we wrap up the design opportunities of the device with future scenarios.

Keywords

Augmented Sports; Smart Racket;

1. INTRODUCTION

Recently, a number of analysis of sports performance has been conducted due to the development of sensing technology and data analysis method. In particular, thanks to the development of wearable technology, industrial products for consumers are widely spread as well as research applications. The main purpose of those products is to improve sports performance or health promotion. For example, a wrist watch-type device Fitbit can quantify sports activities and provide the intensity and the heart rate during the activities. The Smart Tennis Sensor manufactured by Sony provides the information and analysis of tennis activity. The users can collect how long they played and which type of the stroke they used, how fast the swing speed is, etc. These pieces of information allow the players to think and improve the practice amount and its contents. There is also a similar application for a table tennis that classifies a stroke type and localizes a position of a ball impact [1], [2].

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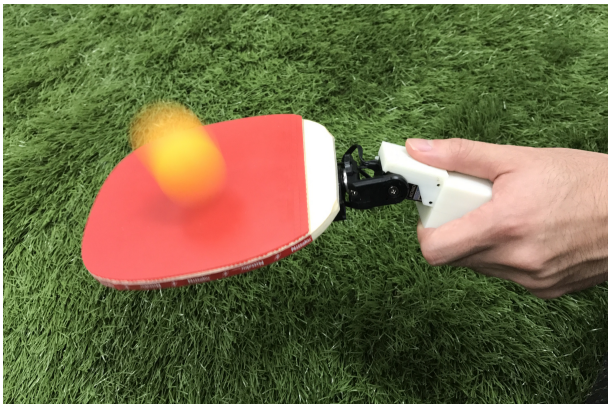

Figure 1: ACTUATE Racket Prototype

However, the method is not interactive and the speed of the intervention with it is slow comparing to a real-time feedback. The real-time feedback can change the user's performance quickly. It can improve their performance or entertain them. A sports coach contributes to improving the performance of players by immediately and directly providing a feedback and intervening with the movement of the players.

In this research, we focus on racket sports. We present an ACTUATE Racket that can change the angle of its surface (Figure 1). We chose to make a prototype using a table tennis racket because of easy integration of sensors and actuators. The prototype racket has an acceleration sensor, a gyro sensor, and a microphone to acquire the racket motion. Based on the sensor data, the angle of the racket surface can be controlled by two servo motors. With the racket, we explore three approaches to intervene the introductory practice "bouncing a ball on a racket". We analyze how these approaches could change the user's behavior and performance.

There are two potential benefits of using the racket especially for beginners and intermediate players. First, various people can enjoy sports by providing the diverse movement. If we can change the difficulty level of sports by the movement of the racket, the new competition structure becomes possible such as beginner vs intermediate player or child vs

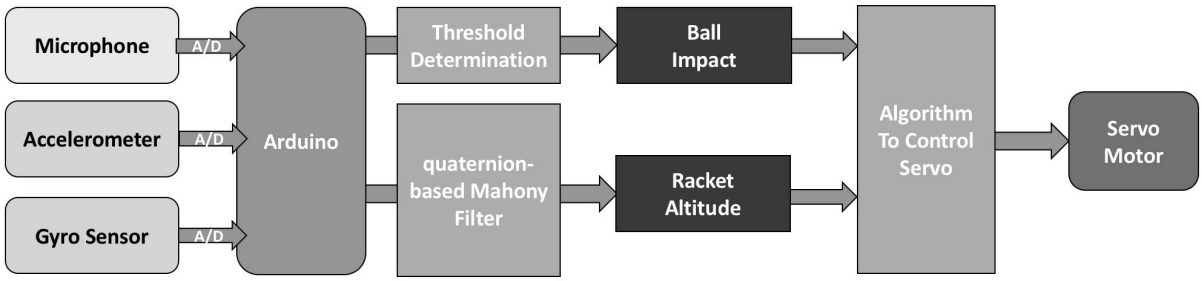

Figure 2: System Diagram

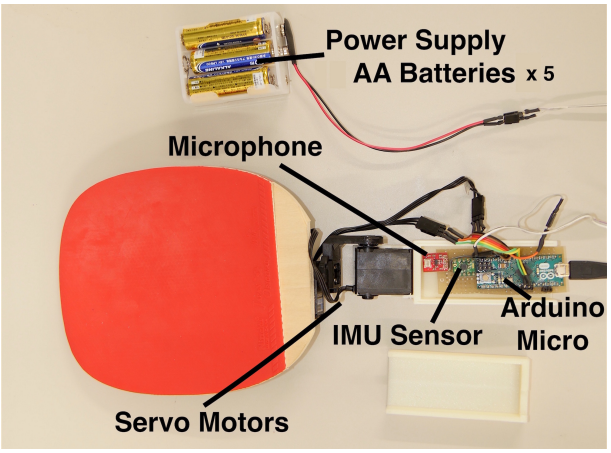

Figure 3: System Components

adult. It increases how players enjoy sports. Second, we can increase motivation to play sports. Since it can induce new diverse movements and interact directly with the user, the racket can motivate users through adding the game element. The motivation can make more people play sports longer. As the good effects on health by doing sports is well known, this can be beneficial for society. It may reduce the medical costs and increase the people's happiness.

The main contribution of this paper is as follows,

1. We created a novel racket prototype that changes the angle of the surface.

2. Using the prototype, we presented three approaches to intervene with the ball bouncing on a racket.

3. We describe the findings and the opportunities through user feedback.

2. RELATED WORK

There are the studies providing users an immediate feedback for their sports activities. Ishii et al. made a reactive pingpong table that provides dynamic graphics and sound. It can augment the experience of the play [4]. Laplacian Vision is a vision augmentation system that can show a predicted ball trajectory to user's optical see through display [5]. It can help to avoid the error of trajectory estimation and to improve user's performance. Regarding a motor skill that is fundamental to playing sports, there is a great review how we should design the visual, auditory, haptic feedback to enhance the learning [9]. Hasegawa et al. developed a device to provide real-time sonification feedback for sking [3]. They showed that the feedback of the center of the gravity of the skier has the potential to improve their skiing skills. The Augmented Climbing Wall [6] is a system that combines computer vision and interactive projected graphics. It explored how interactive technology can change a sport. One of their findings is that the interactive technology can increase the movement diversity and accessibility, and motivate the players.

Yet, there are few kinds of research which interact with users and give the feedback through the equipment they are using during the sports activity although there are various major sports that use equipment such as tennis, golf, and baseball. Moreover, those studies intervene with users focuses on giving feedback through a ball [7], [8]. We focus on the equipment that users hold all the time during the play. The equipment can have embodiment as some of the players feel those equipment are as if they are parts of their bodies. Therefore, it is interesting to explore the design opportunity of the intervention through the equipment they use for sports (e.g. how users feel and react when the tools behave in a new way.)

3. ACTUATE RACKET

ACTUATE Racket is a racket that can change its angle of the surface for creating new interactions of racket sports. In this paper, we aim at exploring the following two challenges through ACTUATE racket.

- How does the intervention of the racket changes the relationship between a player and a racket?

- What is the effect of the intervention?

For this purpose, we developed a table tennis racket prototype (Figure 3). The angle of its racket surface can be controlled based on the racket movement. The system diagram can be seen in Figure 2. It combines a microphone (INMP401 manufactured by SparkFun) to detect the hitting timing, IMU sensor (MPU9250 manufactured by InvenSense) for detecting the motion of the racket, and two servo motors (KRS-3204 manufactured by Kondo Robots) for controlling the angle of the racket surface in 2-axis. To acquire the position of the racket, we applied quaternion-based Mahony filter to the raw data from IMU sensor. The maximum speed of the servo is 0.18sec per 60 degrees. We

used the microcontroller Arduino Micro. For the servo motors, we use the external 7.5V power supply (five AA batteries). The handle of the device is 3D printed (ABS). All sensors and Arduino Micro are inside them. We cut the racket surface of Nittaku Table Tennis Racket and attached it to the servo motor with strong double-sided tape.

4. CASE STUDIES OF BOUNCING A BALL ON THE RACKET

In this paper, we explore training approaches of bouncing a ball on the racket. This is one of the most common approaches to getting beginners familiar with the feeling of a racket and ball. Therefore, it is a good starting point for our research. In addition, there would have enough design space to explore and change some of the task elements even though it is a relatively simple task in playing racket sports. There are many complicated tasks involved in the activity [11]: Users have to perceive the position of the ball correctly, coordinate a racket to its position and bounce the ball with certain amplitude in a rhythmic fashion.

We present three approaches with the racket prototype (1) One approach is to stabilize the angle of the surface during the activity. (2) Another approach is to amplify the angle of the surface regardless of the grip angle while user bounces a ball. (3) The other approach is to intentionally change the surface of the racket for each swing so that a user adjust the angle of its surface.

4.1 Approach 1: Stabilizing the Angle of the Racket Surface

In this approach, we tried to support users to bounce a ball right overhead by stabilizing the racket surface. We lessened the effect of the roll angle of the racket. We only controlled the roll angle instead of the pitch angle. Controlling the pitch angle of the racket is difficult as the pitch angle acquired from the IMU sensor can change with a hit motion during a ball bouncing on the racket. The algorithm is to change the angle of the racket with proportional to the roll angle. We did not completely cancel the effect of the roll to make it parallel to a floor because users sometimes change the angle to correct the trajectory of the ball intentionally.

In this experiment, we had five participants (four males and one female). All of them are graduate students in 20's and not familiar with racket sports. Each user tried a total of six ball bouncing. For three times, user played with Approach 1 algorithm. For the other three times, the user played with the racket, but we did not change the angle of its surface by applying the same voltage to the servo motors during the play. The order was not in turn so as to avoid order effects and practice effects. We asked the users to sit on the office chair with wheels in order to of limit their performance space. Each participant held the device with their dominant hand. The experimenter told each participant to do their best to bounce the ball as many as possible. We recorded the video of all performance for analysis. The experiment was performed indoors (Figure 4).

The result can be seen in Table 1. The performance improvement with the approach 1 was confirmed in two (User A, User B) of the total five users. On the contrary, the two users (User D, User E) decreased the performance with the approach. From the video analysis, we found the result reflects on how frequently users tried to correct a trajectory of the ball. The improved users tried to bounce the ball right overhead while the users whose performance worsened tried to correct the ball more frequently. Based on this, We asked another user who is good at racket sports to try this approach. His performance was worsened with the approach as he often used the strategy of changing the trajectory of the ball with the racket angle. He commented that this approach made his perception of the racket surface deviate. Overall, this method works for the users whose strategy is simply trying to bounce the ball right overhead.

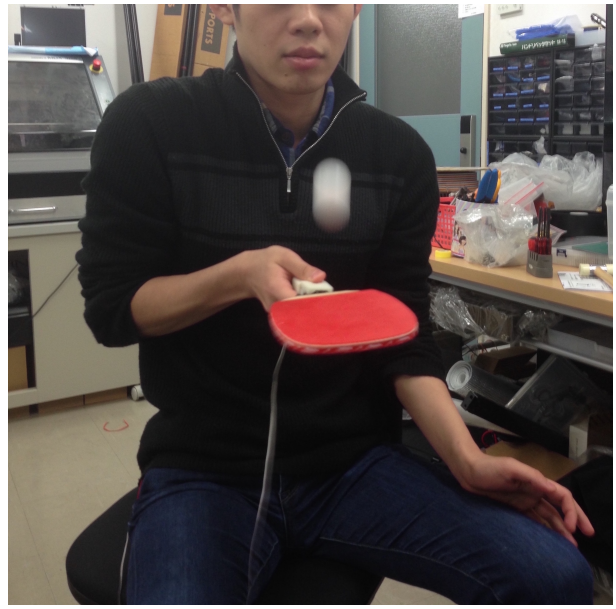

Figure 4: Experimental Setup

Table 1: The Result of Bouncing a Ball with the Racket using Approach 1 (1) and Normal Approach(N)

	Order	Approach 1			Normal		
User A	N11NN1	37	163	180	16	99	33
User B	1NN11N	26	21	16	9	23	7
User C	1NN11N	87	123	190	100	111	194
User D	1NN11N	19	15	11	38	54	9
User E	N11NN1	75	100	112	265	186	167

4.2 Approach 2: Amplifying the Angle of the Racket Surface

In this approach, we tried to induce a specific strategy of bouncing the ball on a racket. We penalized a steep angle and a big movement by amplifying the effect of the roll angle and the pitch angle of the racket with the servo motors. The algorithm is to move the servo motors in order to amplify the angle with proportional to the acquired IMU data if the data go over a threshold. According to [10], the user will improve its performance after the number of trials, but as a strategy, the movement of the racket will be reduced. This means if the user does not move the racket too much, the difficulty level of the task will be lower and users can bounce the ball with stability. We tried users to learn the strategy

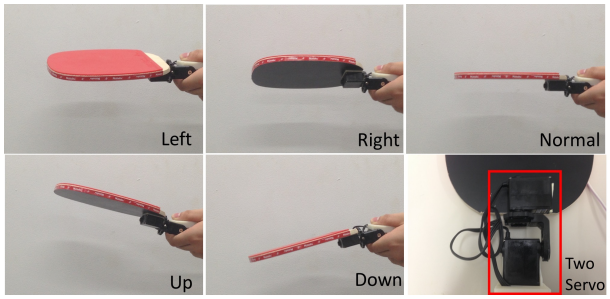

Figure 5: Five States of Racket with Approach 3

of bouncing the ball with a small movement of the racket.

We asked a user with certain experience of playing a table tennis in his childhood to try this approach for 10-15 minutes. We passed the racket and told him to bounce the ball on the racket. We did not tell him how the racket works. We observed that he reduced the amplitude of the bouncing after a couple of trials. Later, we interviewed with him. He commented that he changed the form after he realized how the system works. He said he tried to bouncing the ball with his arm as a pivot point instead of his wrist. He also commented that it helped him to focus on the perception of the racket angle because the racket amplifies the racket of error angle. It suggests the possibility that racket can guide or coach users to do appropriate behavior and to become aware of what user should focus on. We were able to change the interaction between users and their equipment through ACTUATE racket prototype.

4.3 Approach 3: Changing the Angle of the Surface Each Time User Hit a Ball

With this approach, we tried to increase the difficulty of bouncing a ball with the racket. We developed a simple algorithm which changes the angle of the surface when the sound incoming to the microphone goes over a threshold. This allows the angle of the racket to change each time user bounces a ball as the sound of a ball impact goes over the threshold. Because we used two servo motors changed fixed degrees, we prepared five states of the racket angle (normal, up, down, right, left) (Figure 4.3). The order of the change is in turn or at random. A user has to perceive and adjust the angle of the racket surface in addition to a basic ball bouncing task. It makes the task difficult and commands a user to a diverse movement.

We asked two users to try this approach for 10 - 15 minutes. We observed that the change of the pitch angle influences the trajectory of a ball more than the change of the roll angle. After that, we interviewed with them. One user with a little experience of racket sports said it was difficult to continue bouncing, but it was very enjoyable. Another user who had a certain experience of table tennis in his childhood said "I was able to cope with the change in a periodic pattern by adjusting the angle of the wrist because it is possible to predict the trajectory after a couple of trials. It may be effective to learn the perception of the racket surface. With a random change of the surface, it was a good exercise because it was unpredictable and I had to move greatly and quickly. In addition, it can be a good exercise to train the agility. I enjoyed playing with the device as it was like a game." These comments suggest that the device can entertain and motivate users.

5. LIMITATION AND FUTURE WORK

Even though we focus on a simple task of bouncing a ball on a racket, there are interesting design opportunities to support, guide and entertain users. Our future work is how to extend our technology to a real game as there should have more opportunities. For example, if we can support stabilizing the angle of the racket surface when a user hit a stroke or serve, it is much practical. This can improve the player's performance. It is also useful for training because the player can focus on other specific tasks that the technique involves in. By combining the method to unstabilize the racket surface, we can control the difficulty of the game. It creates a new game architecture such as beginner vs intermediate or advanced player, or child vs adult. It is also possible to make a unique team play of a racket sports with ACTUATE Racket. Two users can divide their roles into a player and a strategist. The player hits a ball and the strategist changes the direction of the ball by controlling the angle of the racket surface. It creates a new way of getting involved with a racket sports. Furthermore, by designing the game elements (e.g. a timing of changing the angle, the degree of the racket angle, the direction of the racket angle) for a match, the match can be more entertaining and enjoyable. For example, a user hits a ball with the same form, but a ball goes to a different direction.

The task of bouncing a ball with a racket is simpler comparing to other practical techniques such as strokes and a serve. Those techniques used in real games are more complicated. Therefore we would require more accurate tracking of the racket and ball trajectory, and higher speed control of the racket surface to intervene with these techniques. However, the speed of the servo motor we used is not high enough, which causes latency, and it is impossible to track the ball trajectory with the system. To achieve the above scenarios, we need to improve our racket system and combine motion capture systems and other technologies with them.

6. CONCLUSION

In this paper, we proposed the prototype of ACTUATE Racket and three approaches to intervene with bouncing a ball with the racket. First, we showed that stabilizing the racket angle can support a certain strategy of bouncing a ball right overhead all the time. Next, we found that the racket can guide how user bounces a ball by amplifying the angle of its racket surface. It has the potential to create racket as a coach to improve a player's performance. Finally, we noticed the racket can entertain and motivate users by adding game elements such as randomness. We conclude that there are further design opportunities to play racket sports through the racket that changes the angle of its surface.

7. ACKNOWLEDGMENTS

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