category: research

Computer aided prediction and estimation system for racket performance in tennis

Yoshihiko KAWAZOE, *Saitama Institute of Technology, Japan*

the project

According to the recent news (August 2003), several former top players, including McEnroe, Boris Becker and Martina Navratilova, sent a letter to the ITF encouraging the governing body to revisit the question of rackets. In the letter, the players wrote that tennis has become "unbalanced and one-dimensional." "The sport has lost something, lost some subtlety, some strategy, some of the nuance. Rackets today allow players to launch the ball at previously unthinkable speeds, approaching 150 mph." "The reason for this change is clear to see," they wrote. "Over a period of years, modern racket technology has developed powerful, light, wide-bodied rackets that are easier to wield than wooden rackets were and have a much larger effective hitting area." "They're high-tech weapons made of graphite, Kevlar, titanium and exotic alloys. There's even a racket with a chip racket with a chip built into the handle that allows the racket to stiffen upon impact with the ball. All of this technology has led to major changes in how the game is played at the top level."

Since the sport should be learned from the experience, it is the subjective thing. Accordingly, it is quite difficult to see how the physical property of equipment has an effect on the performance of a player. The terms used in describing the performance of a tennis racket are still based on the feel of an experienced tester or a player even today. However, the optimum racket depends on the physical and technical levels of each user. Accordingly, there are a number of unknowns regarding the relationship between the performance estimated by a player and the physical properties of a tennis racket.

The lightweight racket with handle-light configuration is recent tendency of high-tech rackets, increasing power with an increasing racket swing speed. However, the previous paper of the author showed by using this project that the lightest racket at present in the market has advantageous for racket head speed, but disadvantageous for coefficient of restitution, rebound power, and post-impact velocity for ground stroke, and it has also large shock vibrations at the racket handle compared to the ordinary lightweight racket. This means there is a limit to current lightweight design from the viewpoint of tennis racket performance. The engineers and racket designers at the racket companies seem to be under intense pressure to keep pumping out new and better technologies every year.

This project proposes a computer aided prediction and estimation system for racket performance in tennis. This system is based on the experimental identification of the dynamics of ball-racket-arm system and the approximate nonlinear impact analysis with a simple swing model. It can predict the various factors associated with the frontal impact, such as impact force, contact time, deformation of ball and strings, and also estimates the racket performance such as the coefficient of restitution, the rebound power coefficient, the post-impact ball velocity and the racket stability as well as the sweet areas using a small computer. It is also able to predict and estimate the wrist joint shock vibrations during forehand stroke when the impact velocity and the impact location on the racket face are given.

The predicted results could explain well the mechanism of difference in performance between the various rackets with different physical properties. The predicted waveform of shock vibrations of the player's wrist joint agrees fairly well with the measured one. This system enables us to predict quantitatively the various factors associated with frontal impact between a ball and a racket. It estimates the performance of various rackets with various specifications and physical properties, even with recent innovative complex structures like active piezoelectric fibers.

The fear of McEnroe that technology might get out of hand and spoil the game seems hard to justify in tennis. It was found that the racket-related improvements in play are relatively small and the players themselves continue to improve. There is a gap between a perception and reality. Benefits of racket improvement are real but small, perception exaggerates benefits, and development will continues but limited by physics as A.J. Cochran says in golf.

The result obtained by using this system were reported in many Japanese tennis journals as well as academic journals. It was also introduced for high school physics on National TV. Furthermore, a paper containing the core idea of this project entitled "Experimental Identification of a Hand-held Tennis Racket and Prediction of Racket Vibration during Impact by Y. Kawazoe" was selected as the best paper of *Japan Society of Mechanical Engineers* (*JSME*) in 1995.

This project was supported by a Grant-in-Aid for Science Research of the Ministry of Education, Culture, Sports, Science and Technology of Japan from1995 to 1998, from 2001 to 2003, and a part of this work was also supported by an ITF Grant.

Related images (Illustrations)

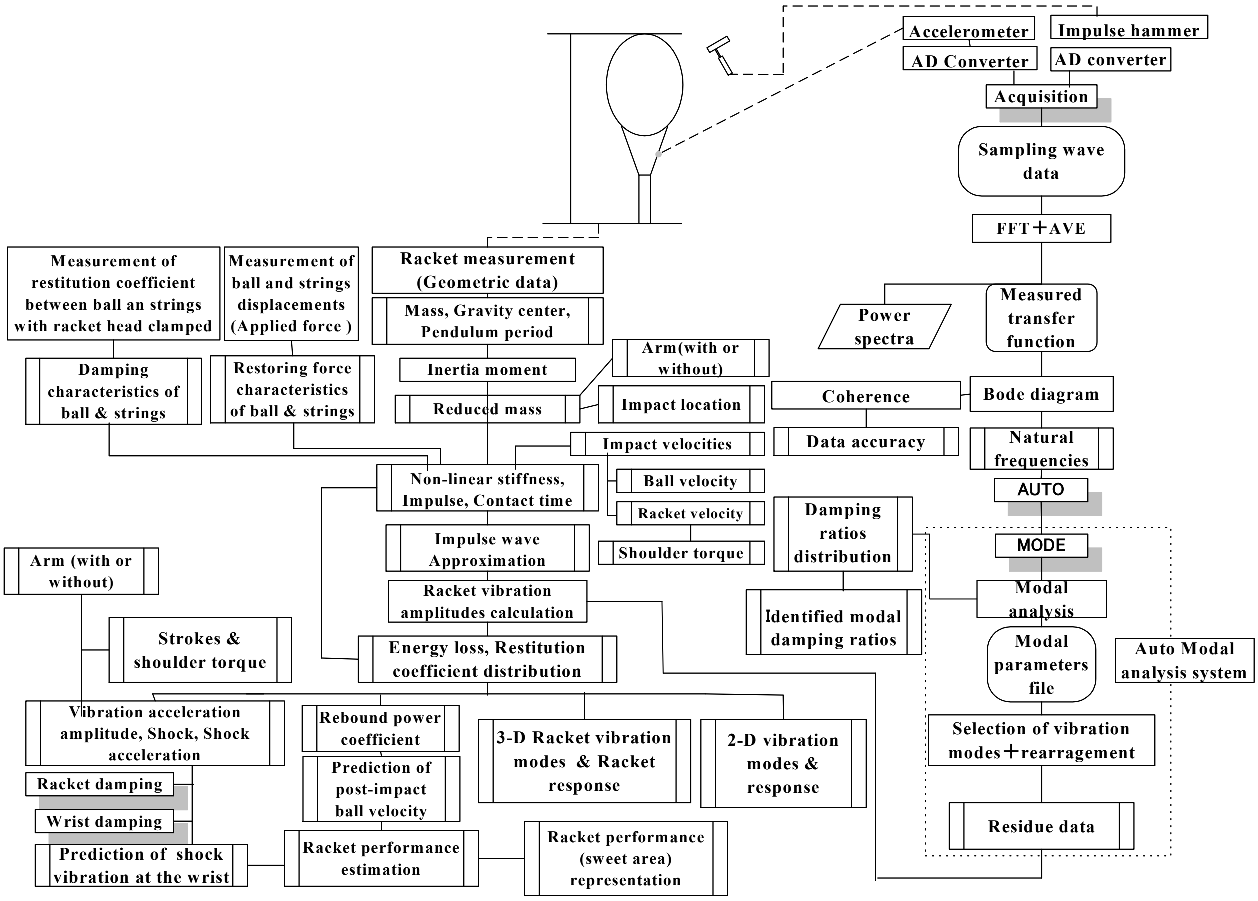


Fig.1 Computer aided prediction and estimation system for racket performance in tennis

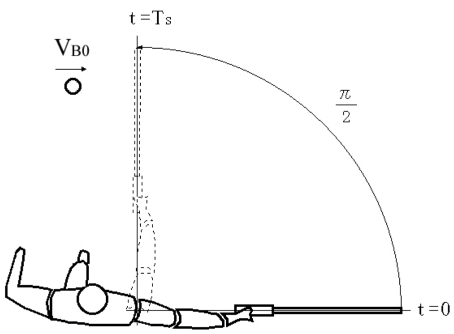


Fig.2 Player's forehand stroke swing model.

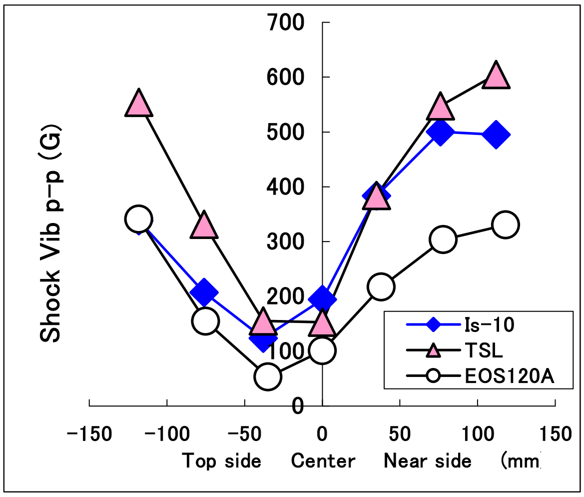
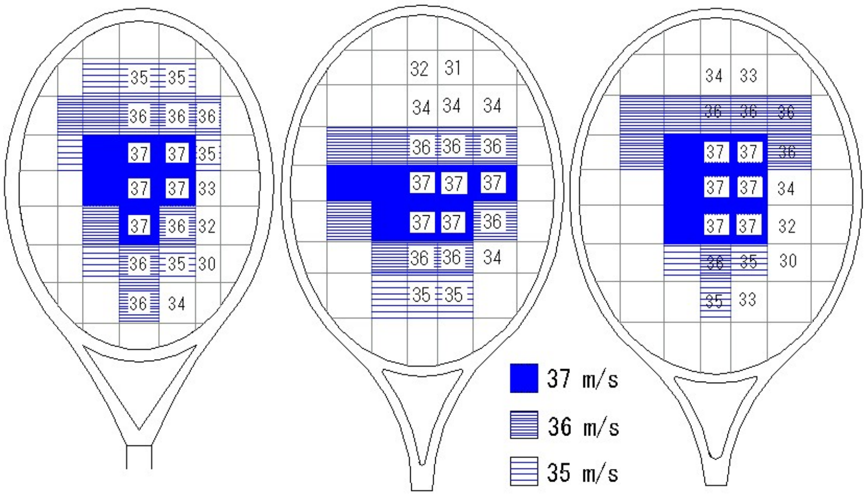
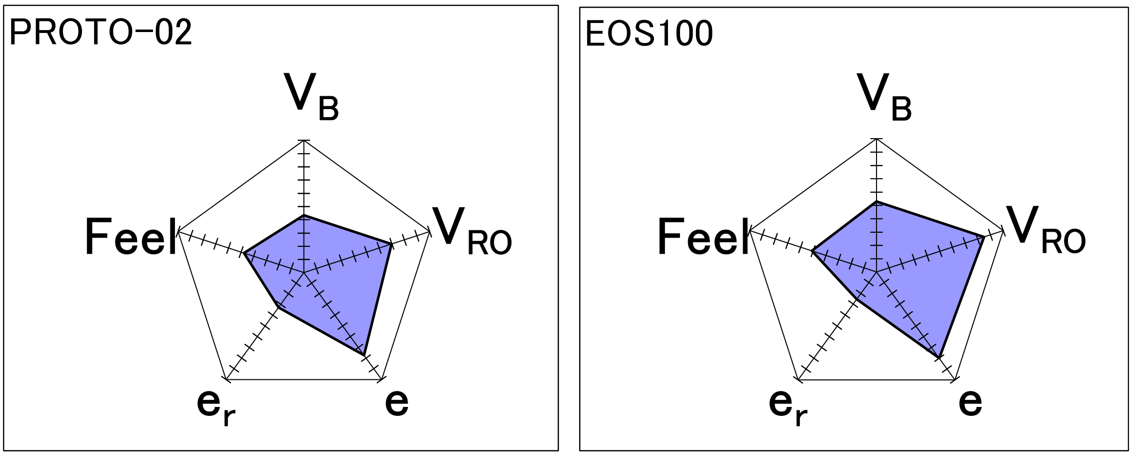


Fig.3 Predicted shock vibrations at the wrist joint when hitting a ball with flat forehand drive at the various impact locations of racket face.



(a) Intelligent fiber Is-10 (b) Lightest racket TSL (c) High power racket EOS120A

Fig.4 Predicted sweet area in terms of post-impact ball velocity V_B
(Shoulder torque Ns = 56.9Nm, coming ball velocity V_{BO} = 10m/s)



(a) Conventional weight and weight balance (b) Light weight high performance racket

Fig.5 Example of performance estimation of rackets with different weight and weight distribution when the ball strikes at the topside of string face during forehand ground stroke.
(e_r: Coefficient of restitution, e: Coefficient of power, V_{RO}: Racket head speed, V_B: Post-impact velocity, or Racket power, Feel: Small wrist joint shock vibrations)

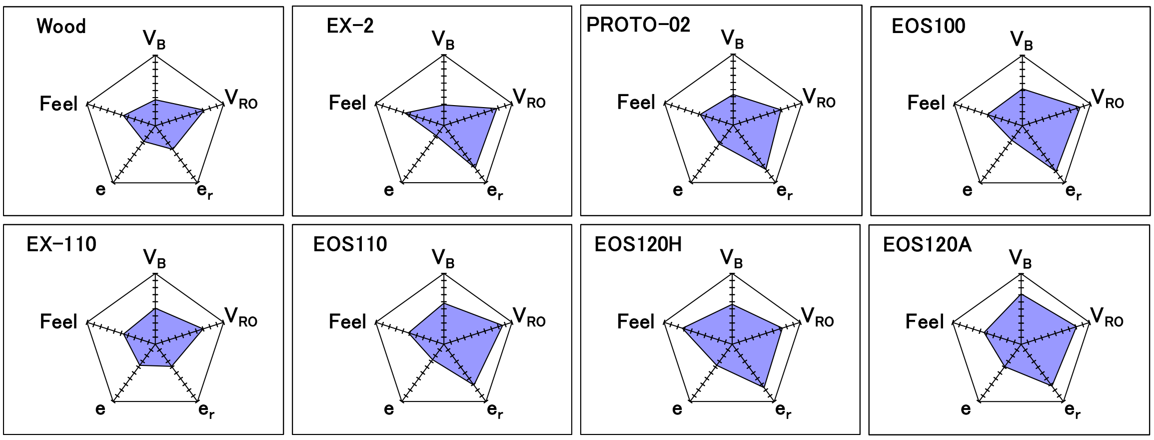


Fig.6 Performance estimation of rackets with different physical properties when the ball strikes at the topside off-center of string face during forehand ground stroke. (e_r: Coefficient of restitution, e: Coefficient of power, V_{RO}: Racket head speed, V_B: Post-impact velocity, or Racket power, Feel: Small wrist joint shock vibrations).

2.

a. What are the benefits of your work to the world of sports and health?

A recent rule change by the ITF has allowed larger balls (7- 8 % increase in diameter while keeping the same mass) to be used in tournaments. The intention of introducing the larger ball is to slow down the flight through the air thus reducing the dominance of the 'big-servers' on fast surfaces such as grass. This system has predicted the waveforms of shock vibrations at the wrist joint with the new large ball compared to the conventional ball during forehand stroke. The simulated results agree well with experimental results. It was found that the contact time of the larger ball is slightly longer and the impact force is slightly smaller. It was also found experimentally and theoretically that the waveforms of shock vibrations with the normal ball and the larger ball are very similar. These results were reported at the 2nd ITF international conference in 2003.

The result of my work has been introduced in some Japanese tennis journals periodically as well as on National TV programs providing the useful information to the equipment users. I am thinking of introducing the useful information in the tennis journal overseas.

b. What are the future potentials of your work?

This project has developed into a system for table tennis. The system for table tennis could also predict impact force, the contact time, the deformation of ball and rubber, the coefficient of restitution, the racket rebound power and the feel associated with the frontal impact when the impact velocity and the impact location on the racket face are given. It made clear the impact mechanism in table tennis where the rebound power coefficient decreases remarkably with increasing impact velocity. Although a player's arm has a remarkable effect on the reduced mass of racket, it has almost no effect on the rebound ball velocity because the mass of a ball is too small compared to the mass of a racket itself. This system was also used to compare the new larger 40 mm ball with the 38 mm ball. The results were reported at the 8th ITTF international conference in 2003.

This project can be applied to the other racket sports such as golf and badminton in the future.

c. In what form could your work be exhibited?

My work could be exhibited in the form of presentation including many useful results for racket manufacturers, tennis coaches and players.

CONTACT

Yoshihiko KAWAZOE,
Professor
Saitama Institute of Technology

Dept. of Mechanical Engineering,
Saitama Institute of Technology,
1690, Okabe, Saitama, 369-0293, Japan

Tel: +81(Japan)-48-585-6824 (Dial in)
Fax: +81(Japan)-48-585-6717 (Dept. Office)
E-mail: ykawa@sit.ac.jp