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Review of ITF-Approved Player Analysis Technology (PAT)

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ABSTRACT

In this article an instrumental review is carried out from a technical/tactical point of view of measuring devices and apparatus applied to tennis. More specifically, a review of the current panorama of the "Player Analysis Technology" (PAT) approved by the ITF (International Tennis Federation) is proposed. The rationale would be the growing importance and application that they are acquiring since the approval of rule 31 by the ITF that allows the use of these PATs in tournaments.

Key words: Player Analysis Technology, International Tennis Federation, new technologies, training.

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INTRODUCTION

Tennis is a sport with specific game characteristics and physical demands. As indicated by Sanz Rivas et al. (2009) "the tennis match is characterised by intermittent exercise, alternating short sets (4-10 seconds) of high intensity exercises and short sets (10-20 seconds) of recovery interrupted by several rest periods of longer duration (60-90 seconds)". That is why in the teaching-learning process of tennis it is very important to know how to quantify and deal with the loads at a technical-tactical, physical, and mental level. For this reason, there has been an increasing use of new analysis tools and their application in the process of game development, which provides evidence of the technical level in real time, allows comparison between different training sessions or matches and the data collected can be shared and communicated on different platforms (Quinlan, 2013).

In 2006, the Hawk-Eye was officially introduced at the Miami, NASDAW-100 ATP Open tournament in Miami, which set a revolutionary technological precedent within the sport that served as a precursor to many other technological innovations (Gellard et al., 2018) and which has proven to be a very useful tool for both chair umpires in their work and for the player's coaching staff as a means of assessing player performance (Baodong, 2014; Gellard et al., 2018).

As a consequence of the implementation of Hawk-Eye, in 2014 the ITF incorporated Rule 31 into its regulations which allows players to wear "smart" equipment in tournaments. Devices placed around the court to track the player are also permitted. Only ITF-approved PAT devices are allowed during competition (Tennis Industry, 2014; ITF, 2019). This Rule 31 is supplemented by Appendix III of the ITF Rules and Regulations which defines "Player Analysis Technology" as any equipment that can perform the functions of recording, storing, transmitting, analysing, and communicating with the player during a match. Such information must be accessible to the player in accordance with Rule 30 (coaching) and Appendix II (The Racket).

This Player Analysis Technology can measure and compare a wide variety of time-based, performance-related variables divided into three groups in relation to:

- **Player.** The primary variables are position and acceleration; stride length and frequency; heart rate; and sweat rate. Secondary variables refer to total and average distance travelled; work-rate; and sweat rate (Reilly, 2005; Ugarte, 2014) and energy consumption. As tertiary variables, an example would be fatigue.
- **Hitting.** Primary variables are the position and orientation of the racket. Secondary variables are the point of impact of the racket with the ball; the type of stroke (serve, volley, forehand, backhand), type of spin (slice, topspin); and power (of the racket).
- **Ball.** The primary variable is position. Secondary variables comprise trajectory; speed; and outcome (in or out). The tertiary variables consist of outcome; match time; and match simulation.

These technologies have been submitted by a total of 19 companies from 14 different countries, including Austria, Czech Republic, Finland, France, Germany, Poland, Slovenia, Spain, Switzerland, and Great Britain in Europe; Hong Kong, Israel, and Japan in Asia; and the United States in America. Finland, France, the UK are home to two developers and only the US has three companies on this list.

This article presents the different TAPs approved to date by the ITF, grouped by category. In addition, some of their characteristics, such as the variables that these devices are capable of analysing, will be discussed in more detail.

METHODOLOGY

For the procedural review of these devices, the list of PATs has been deepened in January 2022 with a total of 28 products. In the document "Player Analysis Technology Overview" (ITF, 2019) establishes three distinct categories:

- **Integrated equipment.** Equipment that can be worn or used on court by players. This includes clothing, wearables; tennis-specific equipment (e.g., rackets); and non-tennis specific equipment (e.g., heart rate monitors, activity monitors).
- **Remote equipment.** Any device not carried or used by the player (e.g., camera-based player tracking systems).
- **Auxiliary equipment.** Equipment that does not record player performance information but can perform any of the other PAT functions, such as tablets, mobile phones and the software that operates on these devices.

Disregarding the ancillary equipment that may be required for each of these approved technologies, we find that there are 19 in the first group and 9 in the second. A separate grouping will be made based on the type of device technology.

RESULTS AND DISCUSSION

Table 1 gives an initial classification of these devices according to the type of equipment. Of the total of 28, 19 are distinguished as integrated equipment and 9 as remote equipment.

Table 1

Grouping of ITF-approved PAT teams based on equipment type.

INTEGRATED TEAM	REMOTE EQUIPMENT
Armbeep	Bigbow Camera System
Artengo Personal Coach	Billie Jean King Cup match insights App
Babolat Play Aeropro Drive	eyes3 For Tennis Pro
Babolat Play Pure Aero	Flightscope Player Tracking
Babolat Play Pure Drive	Foxtenn Diamond Player Pro-Performance Court
Babolat Play Pure Drive V2	Hawk-Eye
Babolat Play Pure Drive Lite	Playsight Smart Court
Babolat Pop	Wingfield
Bigbow Basic Sensor	Zennis
Bigbow Champion Sensor	
Catapult Optimeye S5	
Catapult Vector	
Firstbeat	
Head Tennis Sensor	
Kitris Kit	
Kitris Kit Bia	
Sony Smart Tennis Sensor	
Whoop	
Zepp Tennis	

A second distinction will be made based on the type of solution. Thus, a distinction will be made between racket sensors (integrated in the racket as standard, integrated in the racket, in the handle, in the strings, on the wrist); wearable sensors other than wrist sensors; umpiring systems, tracking systems, statistical applications and game analysis applications; "smart courts" systems; score trackers either on a wristband, an auxiliary device or specific hardware on court and sports smartwatches or compatible bracelets. Based on this distinction, the different devices will be presented in groups.

Among the different racquet sensors is the Artengo Personal Coach (2014) (Figure 1), developed in France, which consists of two separately available devices, the first of which is a 24-gram weight sensor, adjustable to all types of racquets (ITF, 2019). The information can be seen after the training session on a computer or in real time on the second of the two devices, a watch which, in addition to the tennis functions in training or match mode, can be used as a heart rate monitor to measure heart rate as well (ITF, 2019). (Diario, 2013; Europa Press, 2013; Tennis-Technology, 2020a). Significantly, however, it is currently not available in Decathlon shops, nor is it available in the Artengo catalogue.

Figure 1. *Artengo Personal Coach (2014).*

Sony (Japan), on the other hand, brought to market another smart sensor, its Sony Smart Tennis Sensor (2014) (Figure 2), for rackets that can be attached to the end of the grip of Wilson, Yonex, Prince and Head rackets (Sacristán, 2015; Tennis-Technology, 2020c; Vts-tennis, n. d.).

Figure 2. *Sony Smart Tennis Sensor (2014).*

For its part, Babolat, together with its development partner PIQ Sport Intelligence (Businesswire, 2016) marketed the first smart racquet, the Babolat Play Pure Drive (2014) (Figure 3), which comes standard with a built-in smart device. (Dominik, 2020; Tennis-Technology, 2020b). Babolat is expanding its smart racket portfolio in 2016 with the new version of its previous model, the Babolat Play Pure Drive V2, as well as the new Babolat Play Aeropro Drive, Babolat Play Pure Aero and Babolat Play Pure Drive Lite. To point out that from the ITF website (ITF, 2019) you can download the different certificates of approval but not the reports, you can only download the report of the first model.

Figure 3. *Babolat Play Pure Drive (2014).*

ZEPP Labs, USA, developed the third ITF-approved smart sensor (2015), adjustable to the end of the racket's grip like the Sony Smart Tennis Sensor, the ZEPP Tennis (Tennis-Technology, 2020d) (Figure 4). Today, however, ZEPP has stopped marketing this sensor and offers only its upgrade, which does not appear on the ITF list (Europa Press, 2017; GizTab, 2017; ZEPP Labs, n. d.-b). Add informatively that this company offers other possibilities within this line of smart sports equipment for other sports such as golf, tennis or football that could be perfectly adapted to the practice of tennis. (ZEPP Labs, n.d.-a).

Figure 4. *ZEPP Tennis (Tennis-Technology, 2020d).*

The Czech company Proavis S.R.O. presented two smart devices in 2016 that are primarily intended to be attached to the end of the racquet handle but are also adaptable to other types of sports equipment: the Bigbow Basic Sensor and the Bigbow Champion Sensor (Figure 5). The main difference between the two lies in the connectivity for data transmission.

Figure 5. *Bigbow Basic Sensor.*

Only one new device is approved in 2018, the Head Tennis Sensor (Figure 6) from Austrian Head developed by Zepp. (Best tennis sensors (updated in 2022!), 2020; Tennis Sensor - HEAD, n. d.; Top 5 best tennis sensors 2020 - track and analyze, 2020).

Figure 6. *Head Tennis Sensor.*

Among the wearable devices, the first device to be approved was the Kitris Kit (Figure 7) from Kitris AG, Switzerland, which is a wrist device that serves as a scoreboard, audio record of how points were won and lost, and voice recorder for capturing mid-game notes. (KITRIS, n. d.). To ensure that this device does not violate ITF Rule 30, which prohibits on-court coaching, on-court recording and notes cannot be accessed. (Tennishead, n. d.).

Figure 7. *Kitris Kit.*

In 2015, Kitris AG introduced an upgrade to their device, the Kitris Kit Bia (Figure 8). Currently, only this upgrade is marketed on their website under the name Kitris Kit (KITRIS AG, n. d.-a). From what they advertise, it seems that Kitris has refocused their offer from tennis to sport in general by offering an easy to install "plug & play" system offering a product similar to Playsight Smart Court (KITRIS AG, n. d.-b).

Figure 8. *Kitris Kit Bia.*

For its part, Babolat presented a smart wrist sensor, the Babolat Pop (2015) (Figure 9) that can be worn either under a normal wristband or sheathed inside an accessory wristband that comes with it (Private Sport Shop, n. d.; VTS Tennis, n. d.).

Figure 9. *Babolat Pop.*

In 2019, the Slovenian company Biometrik D.O.O. Armbeep was approved. (ITF, 2019; Tennis analytic system, 2020) (Figure 10).

Figure 10. *Armbeep*

In the same year, two new devices arrived from Catapult PTY. Ltd (Figure 11). Catapult introduced its Catapult Optimeye S5 sensors (Fernández-García & Torres-Luque, 2018) and Catapult Vector, which are worn inside a bib worn by the athlete. The data is captured by a receiver and can be viewed through the Catapult OpenField software on an auxiliary device in both cases or also through a smartwatch or smartphone with the Catapult Vector app in the case of the Catapult Vector. The Catapult company is not limited to the tennis market and offers several other products easily applicable to racquet sports that are not listed by ITF (Catapult, n. d.; Catapult Support, n. d.).

Figure 11. *Catapult PTY. Ltd.*

In 2020, Finland's Firstbeat Technologies OY unveiled its Firstbeat device (Figure 12). Unlike the Catapult sensors, this one is integrated with a chest strap. (ITF, 2019; You have it in you, n. d.). Data can be accessed through two apps in different ways. The Live app allows coaches to view and obtain data from multiple players simultaneously. (Introducing Firstbeat Sports Sensor and Live app, n. d.). The Sports app app (Firstbeat Sports Standard + Sensor, n. d.) allows players to log in individually to a personal account and access their own coaching information (ITF, 2019).

Figure 12. *Firstbeat.*

Also in 2020, the US-based Whoop Inc. certified Whoop 3.0 (Figure 13) (ITF, 2019). Currently, the company markets version 4.0, which is not registered in the list (WHOOP, n. d.).

Figure 13. *Whoop 3.0.*

Within the refereeing systems, in 2013, the Hawk-Eye (40) (Figure 14) (Great Britain), consisting of a system of multiple video cameras (8-10), personal computer, two-way radio with intercom panel, in-stadium display and auxiliary device (smartphone) was approved (ITF, 2019).

Figure 14. *Hawk-Eye (40).*

In 2017, Foxtenn BegreenS.L. introduced the first and so far only Spanish smart technology applied to tennis with its Foxtenn Diamond Player Pro-Performance Court system (Figure 15) which uses multiple high-speed cameras and high-frequency laser scanners placed around the court connected to a server to capture player and ball trajectories (Foxtenn Diamond System, n. d.; ITF, 2019). The system can optionally be connected to audio output and data can be displayed through auxiliary devices. Compared to the Hawk-Eye, it allows to visualise the live spot and the impact of the ball with the ground with millimetre accuracy instead of working with triangulations via cameras (Rigueira, 2017; Serras, 2017). Their website differentiates two types of solutions for the Foxtenn Diamond system today, one focused on tournaments and professional players and another for academies and players in training (Foxtenn Diamond System, n. d.).

Figure 15. *Foxtenn.*

The Flightscope Player Tracking (Figure 16) from Poland's FlightScope SP Z.O.O., 2017 also became the third electronic line arbitration system to meet the criteria set by the committee (About FlightScope Tennis, n. d.; Ramos, 2020). The software reconstructs player positions in three dimensions from multiple camera images; player position data is used to generate coaching information including distance travelled, player speeds and court coverage and can be transmitted to the stadium screen, television or other devices via the internet (ITF, 2019). It should be mentioned firstly that this company also uses its technology in other sports; and secondly that the listed link does not work and that they seem to be implementing a new solution with this technology for the current year 2022 (FlightScope tennis, 2022).

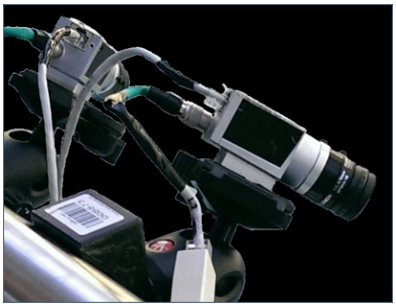

Figure 16. *FlightScope Player Tracking.*

Among the "smart courts" solutions is the Playsight Smart Court (PlaySight, n. d.) (Figure 17) developed by Playsight Interactive LTD in Israel (2014), a fully automated on-court monitoring system that offers line shot umpiring, live streaming, multi-angle video replays with the possibility of video analysis and detailed game statistics offered in an interactive court-side display unit (Gellard et al., 2018) which turns the court into something we could call a "smart court".

Figure 17. *Playsight Smart Court.*

In 2019, the Wingfield from the German company Wingfield GmbH is approved, which is another integrated solution that turns the tennis court into a "smart court" (ITF, 2019; Making tennis smart, n. d.). This system consists of two cameras on both sides of the net and another one on one of the back courts connected to a kiosk at the side of the court, next to the net. The software reconstructs the players' positions and ball trajectories in three dimensions from the incoming images. The useful training information is not displayed on the box, but on the Wingfield App via an auxiliary device.

As tracking systems, 2016 saw the introduction of the Bigbow

Figure 18. *Making tennis Smart.*

Camera System (Figure 19), a system composed of multiple smart cameras connected to a server using the BigBow Manager software which displays the position of the ball and players in three dimensions, ball speed and identification of ball impacts (racket and court).

Figure 19. *Bigbow Camera System.*

In 2017 the eponymous Finnish company presented its Zenniz device (Zenniz, n. d.) (Figure 20) consisting of multiple microphones placed around the court connected to a central unit that houses a touchscreen user display and speaker that allows the ball trajectories to be reconstructed in three dimensions. The information displayed on the screen depends on the selected mode (ITF, 2019). From what they present on their website, they seem to have evolved the system to offer a kind of "smart court" similar to what is offered by Play Sight by now integrating the screen into a kiosk at the court side and incorporating cameras also to offer video analysis (Zenniz, n. d.). Apart from offering a line refereeing system and live statistics it also offers interactive training exercises (Zenniz, n. d.). However, these improvements are not reflected in the official list of approved PATs.

Figure 20. *Zenniz.*

From Hong Kong comes the Eyes3 For Tennis Pro system from Infinite Cube (Figure 21), a portable electronic VAR and line umpiring system (Eyes3 Fair Play technologies for sports, n.d.; ITF, 2019). The difference between this system and the rest is that no specific hardware is needed and it can be quickly set up on the court and at a lower cost; however, it requires auxiliary devices, at least eight mobile phones as image capture devices and another as a control device (Eyes3 Fair Play technologies for sports, n.d.; ITF, 2019). A negative aspect is that they only work on Apple operating systems (ITF, 2019).

Figure 21. *Eyes3 For Tennis Pro.*

Finally, as a last PAT, in 2021 US giant Microsoft released its Billie Jean King Cup Match insights App (Figure 22) that combines live scores with ball/player tracking data to provide near real-time coaching information to an ancillary device (Billie Jean King Cup- Microsoft powers data and insight at Billie Jean King Cup Finals, n.d.; ITF, 2019).

Figure 22. *Billie Jean King Cup Match Insights App.*

This results in the following grouping.

Table 2

Grouping of ITF-approved PAT teams based on solution type.

Integrated equipment			Remote equipment		
Racket sensors	**Wearable devices**	**Arbitration systems**	**"Smart court" solutions**	**Tracking systems**	**Applications**
Artengo Personal Coach	Kitris Kit	Hawk-Eye	Playsight Smart Court	Bigbow Camera System	Billie Jean King Cup Match Insights App
Sony Smart Tennis Sensor	Kitris Kit Bia	Foxtenn Diamond Player Pro-Performance Court	Wingfield	Zenniz	
Babolat Play Pure Drive	Babolat Pop	Flightscope Player Tracking		Eyes3 For Tennis Pro	
Babolat Play Pure Drive V2	Armbeep				
Babolat Play Aeropro Drive	Catapult Optimeye S5				
Babolat Play Pure Aero	Catapult Vector				
Babolat Play Pure Drive Lite	Firstbeat				
ZEPP Tennis	Whoop 3.0				
Bigbow Basic Sensor					
Bigbow Champion Sensor					
Head Tennis Sensor					

First, it should be mentioned that the grouping presented based on the type of solution is based on the main function of this technology, and it may be the case that the same product has functions of one or other type of solution.

On the other hand, to analyse these devices in the current landscape, it is necessary to highlight the effects of the COVID-19 pandemic that have affected this niche as well. As mentioned above, Artengo stopped marketing its system. Babolat announced the cessation of sales of its Play and Pop smart devices (PLAY & POP - Discontinuation of connected services, n. d.) due to the bankruptcy of its development partner PIQ Sport Intelligence (PIQ adventure just ended, n. d.). FlightScope was acquired by IMGArena in 2021 (Sports services, 2021) which makes the above mentioned change of domain and product vision understandable. It seems that Proavis s.r.o. also undergoes some kind of a reshuffle, which would make it understandable that the domain or its products can no longer be found for sale. (PROAVIS s.r.o. , Praha IČO 25671227 - Obchodní rejstřík firem, n. d.).

Another factor to consider is the product development itself, which may lead the company to replace its product with another product or to integrate it into another type of solution. As mentioned, this has happened with the original Kitris Kit model which has been replaced by the later Kitris Kit Bia under the name Kitris Kit. Zepp, for its part, is marketing the second version of its racquet sensor (having stopped the first one) as well as developing the Head one. Also mentioned, Zenniz seems to have incorporated the use of cameras for a reorientation of its product, although it seems that it will continue to market the approved system. Finally, Whoop has switched to marketing its Whoop 4.0 device, making Whoop 3.0 obsolete. As a result, at the beginning of 2022, only fifteen of the twenty-eight registered products are still on the market, although we could increase this figure to seventeen if we consider the new unregistered models of the Whoop and Zepp products.

CONCLUSIONS

The conclusions of this work are as follows: Firstly, the main game characteristics and specific physical demands of tennis are identified, highlighting the importance in the tennis teaching-learning process of knowing how to quantify and work the loads at a technical-tactical-physical-mental level. In addition, the official introduction of the Hawk-Eye in the Miami tournament and the consequent drafting of Rule 31 in the ITF regulations that allows players to use "intelligent" equipment in official tournaments is also discussed. The different player analysis technologies that have been approved by the ITF up to the beginning of 2022 are also analysed, with a total of 28 of them, 19 as integrated equipment and 9 as remote equipment. It should be noted that only fifteen of the twenty-eight registered are still on the market, although there would be seventeen if the new unregistered models of two of these devices were to be considered.

On the other hand, these technologies include racket sensors (integrated in the racket as standard, integrated in the racket, in the fist, in the strings, on the wrist); other wearable sensors apart from wrist sensors; umpiring systems, tracking systems,

statistical applications and game analysis applications; smart court systems; scoreboards either by wristband, auxiliary device or specific hardware on the court and compatible sports smartwatches or bracelets. Likewise, it is highlighted that the use of smart devices in tennis can be of great help to the training process and that their choice will depend fundamentally on the parameters to be monitored and the target audience of the tennis player. Likewise, some direct effects caused by the COVID-19 pandemic can be observed. After the closure of the Babolat Play line, smart rackets are no longer available, although there is still a good supply of smart sensors. Also, some market trends towards offering integrated systems, smart courts, and diversification of solutions to also cover other sports are evident.

A possible extension and complementary avenue would be to review other PAT solutions that are not on the ITF list. Another possible avenue for expansion would be to analyse the devices according to the analysis variables. A proposal to liberalise and promote the use of racket sensors would be the standardisation of the hole at the end of the racket handle, which would make it easier to use the sensor of the player's choice on any racket. With a target group of non-professional users in mind, new integrated systems could be investigated with the minimum specific hardware that would encompass an integrated plug and play solution, a smart court with an on-court referee system and scoreboard and/or auxiliary device, compatible with sports smartwatch devices, chest straps and racket sensors and connection to some kind of platform for statistical analysis, video analysis of the player and online social platform and also the possibility of carrying out fitness or off-court training. Another possible proposal for non-professional users would be the creation of an application for smartwatches at a relatively low cost and offering what tennis players in training or regular players demand.

CONFLICT OF INTEREST AND FUNDING

The author declares that he has no conflict of interest and that he did not receive any funding to carry out the research.

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