# Low-cost motion sensing of table tennis players for real time feedback

Eric Boyer[1,2], Frédéric Bevilacqua[1], François Phal[3] and Sylvain Hanneton[3,4]

[1] STMS Ircam - CNRS - UPMC, Ircam, Paris, France
(+33-1-44-78-48-84; E-mail : eric.boyer@ircam.fr)
[2] Laboratoire de Neurophysique et Physiologie, CNRS UMR 8119, Université Paris Descartes, Paris, France
[3] UFR STAPS, Université Paris Descartes, Paris, France
(E-mail: francois.phal@free.fr)
[4] Laboratoire de Neurophysique et Physiologie, CNRS UMR 8119, Université Paris Descartes, Paris, France
(+33-1-42-86-22-25; E-mail: sylvain.hanneton@parisdescartes.fr)

**Abstract**: we present a motion capture device to measure in real-time table tennis strokes. A six degree-of-freedom sensing device, inserted into the racket handle, measures 3D acceleration and 3-axis angular velocity values at a high sampling rate. Data are wirelessly transmitted to a computer in real-time. This flexible system allows for recording and analyzing kinematics information on the motion of the racket, along with synchronized video and sound recordings. Recorded gesture data are analyzed using several algorithms we developed to segment and extract movement features, and to build a reference motion database.

**Keywords**: sonification, movement analysis, biomechanics, sensors, motor learning, auditory feedback, gesture, sound.

## 1. INTRODUCTION

There is a growing demand for visualizing and analyzing data in sports sciences whether it is for professional athletes to enhance their performance, educational applications or entertainment. We present here a motion capture device we applied to table tennis that was originally developed for gestural control of sound and music.

Most studies dealing with table tennis techniques and players movement analysis used video analysis [1], high-speed cameras for slow motion [2] or motion capture systems [3]. Kinematics data such as velocities and accelerations were therefore estimated based on position and displacement with differential calculus [4]. We propose here to use inertial sensors to measure and analyze players' movements, namely three-dimensional accelerometers and gyroscopes. Such sensors have been integrated in tennis rackets and golf club [5-6] for sensing acceleration rates and swing speed.

## 2. MOTION SENSING SYSTEM

The motion sensing system we developed is based on wireless inertial measurement units (IMU) embedded in the rackets. IMU are nowadays available at low cost and can measure angular velocity (gyroscope) and acceleration (accelerometer) at sufficiently high sampling rate. Compared to motion capture systems based on camera, IMU are largely superior in terms of cost and ease of use for our application where fast and relatively small wrist motions must be analyzed in real-time.

Accelerometers measure a value that contains two components: a "dynamic" acceleration corresponding to $2^{nd}$ derivative of the position relative to a given axis, and a "static" acceleration which depends on the orientation of the sensors to the gravity. The proper acceleration may thus differ from the coordinate acceleration, which is calculated by derivation on spatial coordinates and displacement. A gyroscope is a device that measures an angular velocity around a rotation axis. Three-axis gyros deliver angular velocities around x, y and z axis.

IMU necessitates the need to modify the racket to embed the sensors in the handle. This is relatively easy to achieve for experiments without modifying significantly the shape and weights of the rackets. In particular, we used a small version of wireless motion sensing modules called mini-MO that was designed for digital music instruments [7-8]. Such modules were used to equip all sort of musical instruments such a violin bow [9] or everyday objects like sport balls [10].

Technically, the mini-MO contains a 3D accelerometer (Analog Device ADXL345) and a 3-axis gyroscope (InvenSense ITG-3200). These sensors are integrated in a custom electronic card (4×3 cm) that also contains a module (Jennic OEM JN-5139) that process
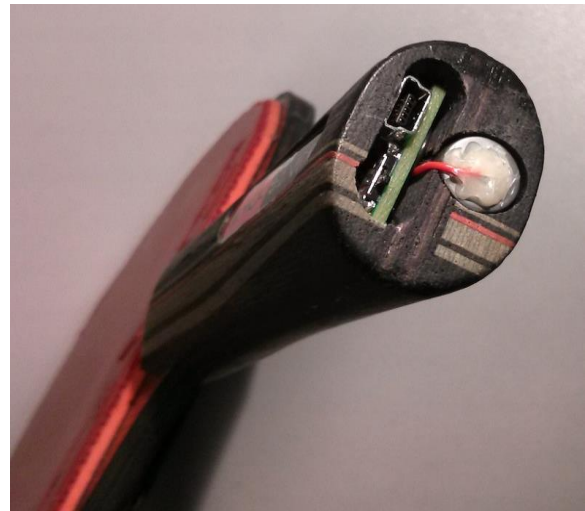


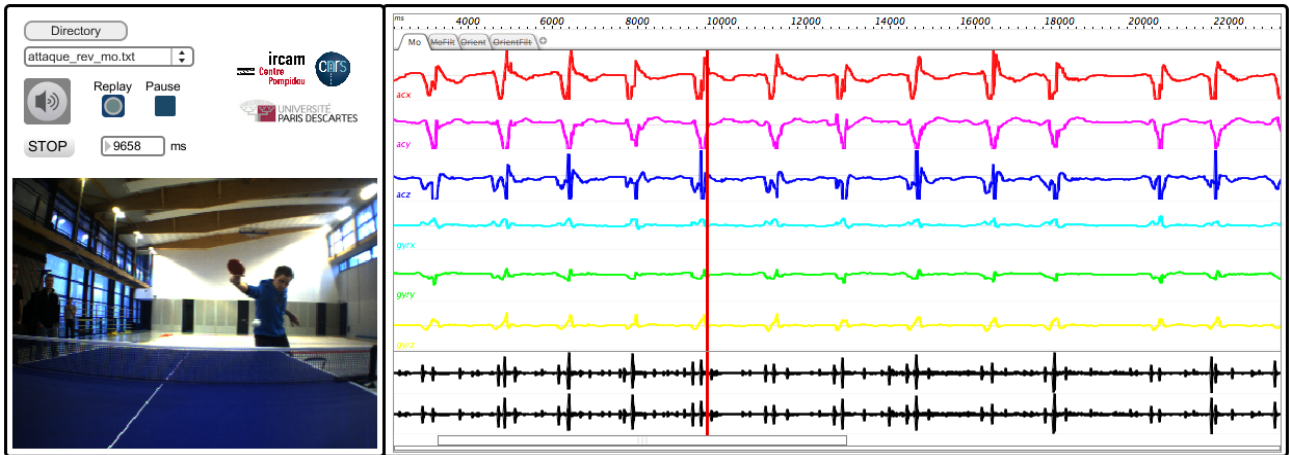Fig. 1 View of a racket prototype with a mini-MO and its battery inserted in the handle.

Fig. 2 Screenshot of the interface developed for visualizing the measurements and aligned media tracks. The top six curves are accelerations and angular velocities for X, Y and Z axis respectively. The waveform of the audio recording is visible at the bottom. The vertical cursor allows scrolling forward and backward while all tracks are played synchronously. Control panel is visible at top left and video window at bottom left.

and transmit the data wirelessly using the IEEE protocol (2.4 GHz band). The unit is powered using a rechargeable battery. Fig. 1 shows a picture of our prototype.

Y axis is parallel to the racket handle directed toward the top of the racket, Z is normal to the racket surface directed out from the red covering and X is perpendicular to the racket handle oriented so that (X,Y,Z) is a direct Cartesian coordinate system. The origin of the axis is the IMU circuit board itself. The coordinate system is thus attached to the racket.

Data are transmitted to the host computer running a recording software programmed with Max/MSP [11] and using UDP and OSC [12] protocols. Data were recorded at 10 ms sample rate along with video and sound of the performance. Video was recorded with an IEEE-1394 camera (Pointgrey Research, FL2-03S2C) at 30 frames per second. Ambient sound of ball bounces on the table and strokes on the racket surface was recorded using a AKG CK91 capsule on a AKG SE300B condenser microphone in an Edirol UA-25 audio interface running at 44.1 kHz. The microphone was set at the right of the player, 1.5 m away from the table, approximately as high as the players' shoulders.

## 3. EXPERIMENT

### 3.1 Subjects

Two table tennis players, graduating for Sport Sciences and Technology degree at Université Paris Descartes (Paris, France) participated in the first experiment using the system described in the previous section. They were both 20 years old and both right-handed. A unique session was carried out under normal training session conditions and with the help of their coach.

### 3.2 Experimental procedure

The aim of this preliminary study was to build a first database of gesture and to analyze the movement features that can be obtained with our system. The players were asked to perform repetitive strokes with their coach sending them a ball without spin during practice (no rally). The first player was asked to perform six specific strokes: forehand and backhand drive, forehand and backhand topspin and forehand and backhand push. The second player was asked to perform a forehand and a backhand service. Players were instructed to play until they feel satisfied with at least 10 strokes. We recorded all the gestures continuously. Between 22 and 50 strokes were recorded for each type and 16 forehand and backhand services each.

## 4. RESULTS

A dedicated interface using the software Max/MSP was developed for visualizing and playing back all data streams synchronously (i.e. six-degree motion data from the sensors, sound and video tracks). A screenshot of the interface is presented in Fig. 2. The playback of the gestures allows for simulating real-time data coming from the sensors and building up real-time processes like controlling sounds for example. Moreover, by moving the cursor or jumping to a precise time in the recording, one can browse over the different strokes recorded and play back specific excerpts. Data, video and sound tracks are synchronized together at a position
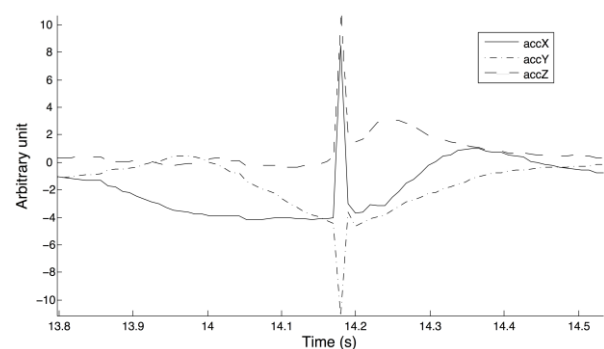


Fig. 3 Raw acceleration time profile on X, Y and Z axis of a forehand drive showing the effect on acceleration of the ball hitting the racket surface.
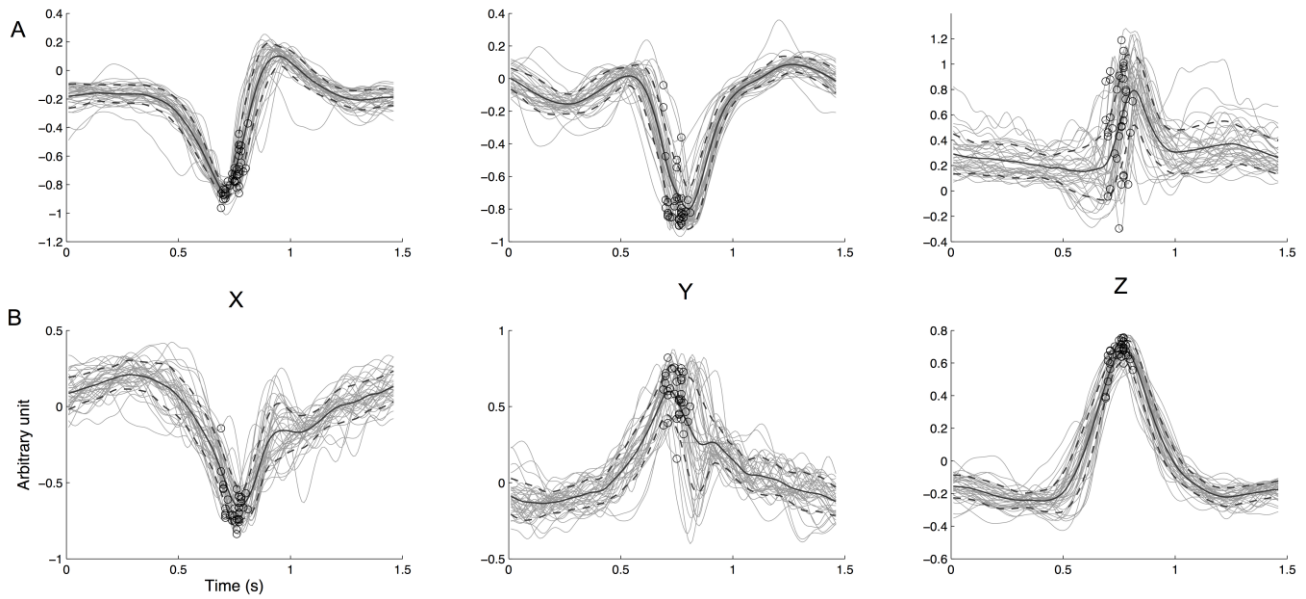
Fig. 4 3D acceleration (row A) and angular velocities (row B) of the 37 consecutive forehand drive strokes, black circles indicating ball hits. Black bold line is the average; dash lines are the average plus and minus standard deviation.

that can be controlled by the cursor, which enable for detailed observations of the player's gesture.

It is possible to detect the moment the ball hits the racket surface [13] directly from the raw acceleration signal. An example of raw acceleration data is presented in Fig. 3 where a sharp peak can be observed, which corresponds to the shock produced by the ball hitting the racket surface. The shock appears, as expected, synchronously on the 3 axis. The amplitude of these peaks appears to be typically two to four times the maximum amplitude of the acceleration signals corresponding to the racket motion. The peak of the ball hit can be easily removed using simple low-pass signal filtering since it has a high frequency content compared to the gesture.

One purpose of constituting a database of players' movements is to find procedures to evaluate the movement repeatability. All raw data were processed with a Gaussian low-pass filter to remove stroke peaks. The complete recordings, containing repetitive strokes, were segmented by finding initiation and termination of the movements in the synchronized video track. Fig.4 shows the superposition of the 37 forehand drive strokes (in grey lines) for the 6 data channels (top graphs from the left are acceleration on X, Y and Z axis, and bottom graphs are angular velocities around X, Y and Z axis). For each stroke the black circle indicates the moment of the contact with the ball. The average across all the movements is plotted in plain black line. The two dash lines represent the mean curve plus or minus the standard deviation. Amplitudes are normalized.
Overall, we found that there is a high repeatability of the player motion, which is illustrated in Fig.4 by the small standard deviation, especially on X and Y accelerations. The Z angular velocity exhibits smaller

and more constant standard deviation over time compared to the X and Y angular velocities. Generally, X and Y gyros data revealed smaller magnitude and slightly higher standard deviation across repetition. This is actually not surprising considering that for this particular stroke, angular velocities of the racket around these axes are not prevailing.

The evolution over time of the standard deviation shows a drop near the ball contact with the racket. This reveals that the player movements are "tuned" around the time of contact with the ball. The player seems to adapt his motion to strike the ball each time in the most consistent manner (depending on his position and the coming ball spin and trajectory).

Our results are concordant with Marinovic et al. [14] who studied with video cameras the velocity of forehand drive strokes under several condition changes (trajectory, velocity and spin of the ball). They concluded that players adjusted their movement toward striking the ball with a maximum velocity. In our study the players actually stroke the ball around maxima and minima of acceleration and angular velocity of the racket. In the case of a forehand drive, the ball hits appear on average 40 ms after the minimum on X axis, and 50 ms before minimum and maximum on Y and Z axis, respectively.

The evolution of the standard deviation observed in the forehand and backhand services revealed smaller values than for the other strokes (typically twice as less). This could be explained by the greater control of the whole motion, since the ball is initially thrown by the player himself, giving a better control on the whole stroke. Less motor adaptation is then required during service, producing reduced variation in the data.

## 5. CONCLUSION AND PERSPECTIVES

This study demonstrates that our motion sensing system, using inertial sensors, is sufficiently precise to study typical table tennis strokes. Our low-cost system can retrieve required information about movement kinematics and detect the ball strokes on the racket. The interface developed stands for a complete multimedia visualization tool available right after a recording without processing needed. Replay also allows for recreating real-time conditions for prototyping further implementations. A preliminary database of gestures has been built up and will be extended to other types of strokes [15] and in different conditions.

This first database aims at creating a framework for developing sonification of player's movements. Our purpose is to give the player an augmented feedback of his movement using the auditory modality. Our hypothesis is that motor control can be supported by an additional sensory feedback [16] and that sound can be an effective and pleasant way to provide information fast enough to embody the player's movement [17-19]. Table tennis players already constantly integrate information about sensory inputs, mainly vision and proprioception, with extremely fast processing and triggering of motor commands. The auditory modality remains largely available without interfering with other modalities and can be processed rapidly. Therefore, sound can be an effective way to provide extra-information in real-time to the player during practice. Combining movement analysis with sonification techniques can provide players with direct information for self-assessment of the quality of strokes or for the intention of the opponent. This allows for new perspectives of the representation of the players' motion.

## 6. ACKNOWLEDGMENTS

## REFERENCES

[1] Rodrigues, S.T., Vickers, J.N. and Williams, A.M. Head, eye and arm coordination in table tennis, *Journal of Sports Sciences*. 20, 187-200, 2002.

[2] Shum, H. and Komura, T. Tracking the translational and rotational movement of the ball using high-speed camera movies. *Proceedings of the 2005 International Conference on Image Processing*, 2005.

[3] Rusdorf, S. and Brunnett, G. Real time tracking of high speed movements in the context of a table tennis application. *Proceedings of ACM Symposium on Virtual Reality Software and Technology*, 2005.

[4] Bootsma, R.J. and Van Wieringen, P.C.W. Timing an attacking forehand drive in table tennis. *Journal of Experimental Psychology: Human Perception and Performance*, 16, 21-29, 1990.

[5] US Patent n° US 7234351 B2, http://www.google.com/patents/US7234351

[6] US Patent n° US 20060052173 A1, http://www.google.com/patents/US20060052173

[7] Flety, E. and Maestracci, C. Latency improvement in sensor wireless transmission using IEEE 802.15.4. *Proceedings of the International Conference on New Interfaces for Musical Expression*, Oslo, Norway, 2011.

[8] Rasamimanana, N., Bevilacqua, F., Schnell, N., Guedy, F., Maestracci, C., Flety, E., Zamborlin, B., Petrevsky, U. and Frechin, J.-L. Modular musical objects towards embodied control of digital music. *Proceedings of the International Conference on Tangible Embedded and Embodied Interaction*, 2011.

[9] Kimura, M., Rasamimanana N., Bevilacqua, F., Schnell, N., Zamborlin, B. and Fléty, E. Extracting human expression for interactive composition with the augmented violin. *Proceedings of the International Conference on New Interfaces for Musical Expression*, Ann Arbor, USA, 2012.

[10] Rasamimanana, N., Bevilacqua, F., Bloit, J., Schnell, N., Fléty, E., Cera, A., Frechin, J.-L. and Petrevski, U. *Proceedings of the 2012 ACM annual conference on Human Factors in Computing Systems*, 2012.

[11] Cycling 74, www.cycling74.com.

[12] www.opensoundcontrol.org.

[13] Sorensen, V., Ingvaldsen, R.P. and Whiting, H.T.A. The application of co-ordination dynamics to the analysis of discrete movements using table tennis as a paradigm skill. *Biological Cybernetics*, 85, 27-38, 2001.

[14] Marinovic, W., Iizuka, C.A. and Freudenheim, A.M. Control of striking velocity by table tennis players. *Perceptual and motor skills*, 3, 1027–34, 1999.

[15] Tepper, G., *ITTF Level 1 Coaching Manual*, 2013.

[16] Todorov, E., Shadmehr, R. and Bizzi, E. Augmented feedback presented in a virtual environment accelerates learning of a difficult motor task. *Journal of Motor Behavior*, 29, 2, 147-158, 1997.

[17] Karageorghis, C.I. and Terry, P.C. The psychophysical effects of music in sport and exercise : a review. *Journal of Sport Behavior*, 20, 54, 1997.

[18] Effenberg, A. Movement sonification: motion perception, behavioral effects and functional data. *Internation Workshop on Interactive Sonification*, pp. 1–4, 2007.

[19] Boyer, E.O., Babayan, B.M., Bevilacqua, F., Noisternig, M., Warusfel, O., Roby-Brami, A., Hanneton, S. and Viaud-Delmon, I. From ear to hand: the role of the auditory-motor loop in pointing to an auditory source. *Frontiers in Computational Neuroscience*, 2013, in press.