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# InPUTTER: CONCEPT AND EVALUATION OF AN ENGINEERED GOLF PUTTER

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***ABSTRACT***

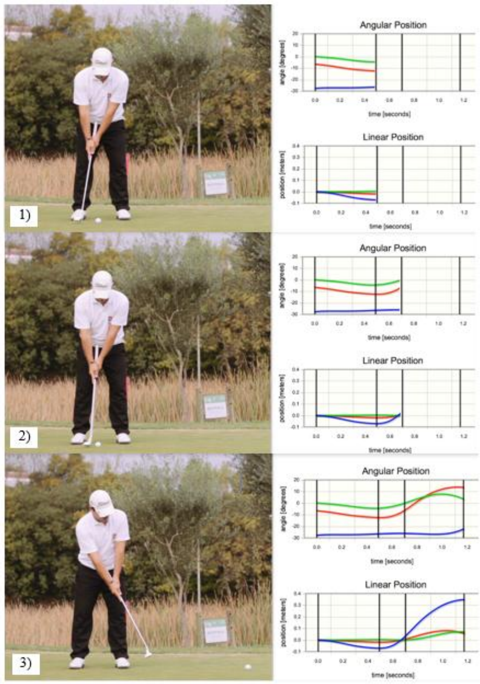
*InPutter was designed for research, analysis and training to improve the performance in golf putting. The engineered putter is equipped with an inertial measurement unit (IMU), force sensitive resistors and heartbeat radio-frequency receiver compatible with Polar electrocardiogram (ECG) transmitters. With a high frequency of 100Hz, the device can be combined easily with other alternatives, such as cameras, to increase the range of applications and variables for further analysis. The putter is able to maintain energy autonomy (battery capacity) for up to four hours, which is ideal for both 'Pitch & Putt' and traditional golf games. After describing the hardware and software development, this article highlights and assesses the benefits of InPutter by validating experimentally its function using the data collected from professional/expert golfers. The data reveals a variety of different putting techniques and strategies. InPutter, with its innovative technologies, is able to measure all aspects of a putting stroke with great precision.*'

**Key words:** Smart putter; Golf putting; Putting signature; Kinematic pattern.

## INTRODUCTION

Golf is one of the most well-known short games in sport, wherein competing players need to introduce the ball into the hole with the fewest number of strikes. According to Pelz, the putting technique, or simply putting, is defined as a light golf stroke made on the green in an effort to place the ball into the hole (Pelz, 2000). Note that this movement represents about 43% of the strokes in a golf game (Dias & Couceiro, 2015). In that sense, authors, such as Pelz (2000), Hume *et al*. (2005), Couceiro *et al*. (2013a) and Dias *et al*. (2014), divide the golf putting movement execution into three phases (Figure 1).

1) *Backswing*: Propulsion of the putter upwards and backwards in relation to the ball. This phase is necessary to position and align the golfer's hub centre and the club head;
2) *Downswing*: Retraction of the putter downwards and forwards in relation to the ball. This phase starts where the backswing phase ends, and finishes immediately before the club head strikes the ball in the correct plane under maximum velocity. Contact/ball impact is the instant when the club head strikes the ball; and
3) *Follow-through*: Starts immediately after the *ball impact* and is the deceleration phase benefiting from the eccentric muscle contraction. This is an inertial phenomenon inherent to the golf putting movement.




1)= Backswing; 2)= Downswing and ball impact; 3)= Follow-through

*FIGURE 1.* **PHASES OF GOLF PUTTING**
Sequence executed by the European Champion of pitch and putting:
Hugo Espirito Santo (Dias & Couceiro, 2015:8)

Although Pelz (2000) states that golf putting is a simplistic movement with little to no struggle regarding its motor execution the same author emphasises that, within such deceptive simplicity, a wide range of variables that can make this quite a complex movement, needs to be taken into account (Pelz, 2000). Notwithstanding the relevance of putting in the outcome of the game, most of the research studied this movement mainly in laboratory settings (Dias *et al*., 2014). On the other hand, alternatives, such as the SAM PuttLab, are costly and far from being portable and easy-to-use (Marquardt, 2007). Therefore, this article presents the development of an innovative smart device, denoted as InPutter, that was designed to provide a professional analysis of putting and not only to “tune” the performance of professional golfers, but to also promote this modality within the context of learning, training and competition. In this sense, InPutter is able to compute the most relevant process variables inherent in putting, thereby providing, in real-time and over the Internet, raw and pre-processed data by benefiting from state-of-the-art methods (Couceiro *et al*., 2013b; Dias *et al*., 2014).

Given the above, the science behind InPutter will be described briefly and the working principles, considered for acquisition and analysis of putting, will be presented. This will include a description of the system architecture, which includes the technical specifications of the hardware and how these are organised. An evaluation of InPutter was carried out, both in terms of putting performance assessment (accuracy and precision of the measures provided), and ecological validity, by considering a sample of 14 professional/expert right-handed adult male golfer volunteers and, under different practice conditions and constraints.

## METHODOLOGY

### Working principles and system components of InPutter

Most of the traditional research around sport science is centred on the product variables (*did the ball enter the hole or not*?). Yet, many researchers have been working towards a better understanding of the process measurements of motor execution (*why the ball did not enter the hole*?). By studying these variables, one may further understand the reasons behind the stability and variability of the final outcome (Dias & Couceiro, 2015).

In brief, as a smart device, InPutter requires minimal configurations, depending on the context and requirements of the golfer, coach or researcher. The following sections describe the acquisition, pre-processing and analysis considered during the design of InPutter.

#### *Acquisition*

This section outlines the data acquisition strategy adopted to analyse all golf putting process variables fully. Considering the limitations of the current state-of-the-art described in the previous section, the acquisition strategy adopted for InPutter focuses on 2 key premises: 1) to provide a high acquisition rate fitted to golf putting; and 2) to enable the acquisition of the data in any context, without any installation or calibration. Regarding its several phases, the literature reveals that golf putting may take approximately between 1 to 2.5 seconds and the linear velocity is always inferior to $1m.s^{-1}$ (Dias *et al*., 2014). Considering an acquisition rate of 100Hz, this data implies that one would be able to obtain about 100 to 250 samples for each put and from each sensing source equipped on the device. On the other hand, in the worst-case scenario of putting with a linear velocity of $1m.s^{-1}$, one could obtain an average error of 10mm. Considering an average putter size of 88.9cm according to PGA (Professional Golfers Association) standards[1], this linear measurement is translated into an angular measurement of approximately 0.6 degrees. Hence, and given the preponderance of angular measurements over linear measurements in this type of pendulum-like movement (Nelson & Olsson, 1986), the acquisition rate of InPutter was defined as 100Hz.

The second premise regarding the portability and usability of InPutter as an acquisition device was guaranteed by embedding all the sensory components, pre-processing and wireless communication within the putter. Without resorting to any pre-installation or pre-calibration, as all other alternatives available in the market, one can start collecting data by simply turning on InPutter. Given that InPutter integrates all data into a single device, the need for any external references is surpassed. In addition, the general InPutter calibration is performed during the development process within laboratory context, thus avoiding any calibration process that may be susceptible to human error. Despite the advantages of InPutter over the alternatives, the analysis of the putting performance still focuses on 3 sensorial

[1]http://www.pga.com/golf-instruction/lesson-learned/putting/putter-fitting-most-important-club-in-your-bag-lesson

sources: an IMU sensor, which includes 3D gyroscope, 3D accelerometer and 3D magnetometer; an array of force sensors; and a heartbeat radio-frequency receiver compatible with Polar electrocardiogram (ECG) transmitters[2]. Hence, the data likely to be obtained, after the initial calibration performed during the development of InPutter, are the angular position (in degrees), the linear acceleration (in $m.s^{-1}$), the impact force on the ball (in KgF.$cm^{-2}$) and heart rate (in beat.$\text{min}^{-1}$). Now it would be necessary to compute any remaining properties to analyse putting in its entirety.

### ***Pre-processing***

It is noteworthy that InPutter already comprises a pre-processing procedure. However, that pre-processing, denoted as low-level pre-processing, is only devoted to the transformation of the acquired measures by benefiting from well-tested mathematical functions provided by the sensors firmware and filtering techniques for the Inertial Measurement Unit (IMU), namely quaternion-based Kalman filtering algorithms (Marins *et al*., 2001). This low-level procedure is necessary to prepare the data for further high-level pre-processing that shall occur on the server side to benefit from more CPU (Central Processing Unit) processing power for real-time data analysis over the Internet.

### **Data analysis of 'InPutter'**

While the Graphical User Interface (GUI), called InPutter Visualiser, allows observation of the putter's trajectory, both raw and pre-processed data can be found by exporting the putting trial to Microsoft Excel. According to the current state-of-the-art, the most relevant properties of these time-series observations, provided by the GUI, are: impact force (KgF.$cm^{-2}$); impact duration ($\mu s$); location of the ball in the putter's face during impact; duration of the movement and each phase (s); amplitude of the angular position (degrees); amplitude of the linear position ($m$); peak of the angular velocity (degrees.$s^{-1}$); peak of the linear velocity ($m.s^{-1}$); peak of the angular acceleration (degrees.$s^{-2}$); peak of the linear acceleration ($m.s^{-2}$); face angle (degrees); declination angle (degrees); and heart rate (beat.$m^{-1}$).

Other complementary measures, such as the impact force applied to each cell of the putter's face or the heart rate over the past 5 readings can be found by exporting the data. Reference should be made to the current literature for a detailed description of all these process variables, which include the works of Pelz (2000), Roberts *et al*. (2001), Hume *et al*. (2005), Couceiro *et al*. (2013a) and Dias *et al*. (2014).

### **System architecture**

InPutter was built in its entirety to be classified as a smart device to provide easy-to-use functionalities, while maintaining its connectivity to the Internet; the putter only needs to be turned on by means of the pressure switch. Two situations may then occur. If InPutter' has not been configured yet with any WiFi network available nearby, it will remain offline. All putting trials made will then be stored in an external memory device (flash memory) and automatically uploaded to Ingeniarius Cloud[3] once it can get connected to the Internet (in

[2]http://www.polar.com
[3]https://cloud.ingeniarius.pt

range of a WiFi network previously configured). When InPutter has been configured with WiFi networks in its vicinities, it will automatically connect to the network with the highest received signal strength indication (RSSI). Setting up a new WiFi network was done by using Texas Instruments SmartConfig technology[4], in which one only needs to be connected to the desired network with another device (for example, smartphone, tablet, etc.), and run the application thereof.

All this plug-and-play and easy-to-use features are only possible due to the hardware choices. Figure 2 shows the technical specifications of the hardware and how it is organised.

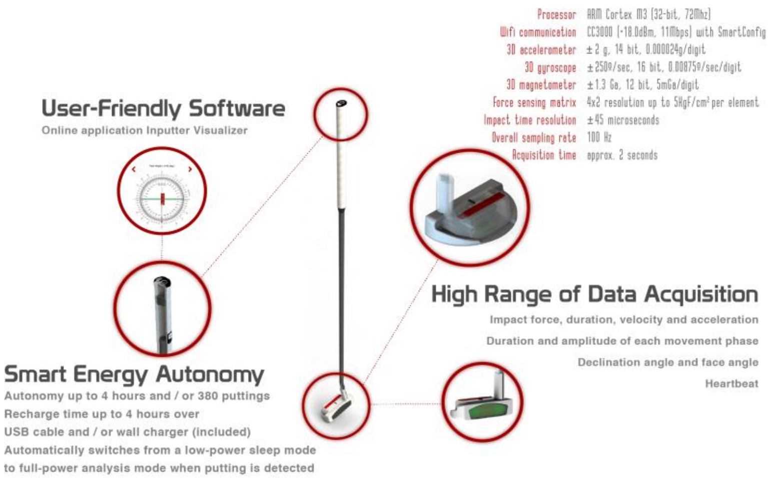



*FIGURE 2.* **INPUTTER HARDWARE STRUCTURE**

**Application of evaluation study**

This study involves evaluating InPutter with a sample of 14 adult male golfers (43.22±13.98 years), volunteers, right-handed and professionals/experts (2.78±1.50 pitch and put handicap).

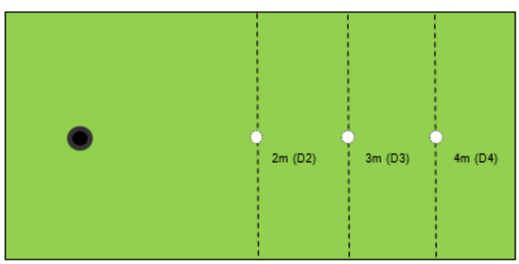



*FIGURE 3.* **EXPERIMENTAL FIELD SET-UP**

[4]http://processors.wiki.ti.com/index.php/CC3000_Smart_Config

The trials were conducted outdoors, on a regular green, at Quinta das Lágrimas Golf Club, Coimbra, Portugal. Three circles, the size of a golf ball, were marked on the green using ball markers, defining the exact location for the execution of the golf putting at 2m (D2), 3m (D3) and 4m (D4) away from the hole (Figure 3).

Each participant performed 3 practise trials at a distance of 2m away from the hole. During this preliminary experiment, the players were not given any verbal feedback about their movement nor about the result provided by InPutter, but they had visual access to the ball trajectory and stopping position. Afterwards, 30 trials were performed at each distance of 2m, 3m and 4m from the hole (a total of 90 trials).

## RESULTS

The results presented will focus mainly on the data provided by InPutter (process variables).

*TABLE 1*. **COMPARISON WITH GOLF PUTTING DEVICES AVAILABLE ON THE MARKET**

| Putting process variables | Values[1] | Dias *et al.*, 2014 | | | InPutter | | |
|---|---|---|---|---|---|---|---|
| | | D2 | D3 | D4 | D2 | D3 | D4 |
| Backswing/downswing[2] (ds) amplitude [mm] | Mean | 171 | 178 | 186 | 174 | 203 | 222 |
| | SD | 36 | 26 | 29 | 38 | 44 | 46 |
| | CV% | 21 | 15 | 16 | 22 | 22 | 21 |
| Follow-through (ft) amplitude [mm] | Mean | 292 | 365 | 414 | 353 | 434 | 481 |
| | SD | 42 | 44 | 52 | 67 | 86 | 88 |
| | CV% | 14 | 12 | 13 | 19 | 20 | 18 |
| Speed of impact (vi) on ball [$m.s^{-1}$] | Mean | 1.14 | 1.28 | 1.41 | 1.47 | 1.74 | 2.02 |
| | SD | 0.18 | 0.15 | 0.24 | 0.16 | 0.25 | 0.22 |
| | CV% | 16 | 12 | 17 | 11 | 14 | 11 |
| Maximum acceleration (am) of putting [$m.s^{-2}$] | Mean | 5.48 | 5.45 | 6.04 | 6.51 | 7.63 | 8.67 |
| | SD | 0.62 | 0.33 | 0.56 | 1.19 | 1.98 | 1.94 |
| | CV% | 11 | 6 | 9 | 18 | 26 | 22 |
| Backswing (bs) duration time [ms] | Mean | 459 | 461 | 559 | 572 | 586 | 607 |
| | SD | 97 | 98 | 140 | 122 | 120 | 140 |
| | CV% | 21 | 21 | 25 | 21 | 20 | 23 |
| Downswing (ds) duration time [ms] | Mean | 290 | 294 | 298 | 304 | 301 | 297 |
| | SD | 59 | 48 | 64 | 77 | 79 | 81 |
| | CV% | 20 | 16 | 22 | 25 | 26 | 27 |
| Follow-through (ft) duration time [ms] | Mean | 437 | 469 | 493 | 400 | 421 | 412 |
| | SD | 91 | 79 | 100 | 112 | 115 | 107 |
| | CV% | 21 | 17 | 20 | 28 | 27 | 26 |

mm= millimetres; m= metres; ms= milliseconds; SD= Standard Deviation; CV%= Coefficient of Variation; $m.s^{-1}$= metres per second (power of -1); $m.s^{-2}$= metres per second (power of -2); [1] Overall results; [2] Amplitudes of both backswing and downswing are the same.

For the experimental evaluation, attention was focused on the most common values presented in the literature (Dias *et al*., 2014), concerning the backswing and downswing amplitude, follow-through amplitude, speed of impact on the ball, maximum acceleration of the put, backswing duration time, downswing duration time and follow-through duration time. It can be observed in Table 1 that the data retrieved with InPutter follows a similar tendency with the distance to the hole regarding the amplitude, velocity and acceleration of the put. However, the duration of each phase does not follow an increasing tendency as was also found by Dias *et al*. (2014).

Two important variables should be considered in this comparison. The study presented by Dias *et al*. (2014) involved a sample of 10 professional/expert golfers and was accomplished in an indoor artificial green, as opposed to the real green used in this work. Moreover, in the study of Dias *et al*. (2014), the data was collected entirely by means of a front camera and semi-manual tracking under MatLab, where human error cannot be ignored. Couceiro *et al*. (2013b) provide a detailed description of the detection and estimation methods considered.

Even if the latter is ignored, the literature is clear that there are differences in putting execution between different players (Sim & Kim, 2010), as well as the effect of artificial and real green surfaces (Drane *et al*., 2014). For instance, according to Delay *et al*. (1997), and as supported by the results in Table 1, the backswing/downswing amplitude of professionals (experts) is considerably larger than that of novice golfers. Another interesting feature provided by InPutter is the reliability and consistency of the data. The variability (SD) is generally smaller than what was observed by Dias *et al.* (2014), meaning that the deviation from the average (AVG) is smaller. This may be explained by the consistency of the kinematic estimation of the putting provided by the quaternion-based Kalman filtering algorithms (Marins *et al*., 2001), and followed by the Levenberg-Marquardt fitting method (Moré, 1978).

## InPutter Visualizer

In this section, the different outputs from the GUI, named InPutter Visualizer, is presented as retrieved from 2 distinct players (Player 1 on the left and Player 2 on the right).

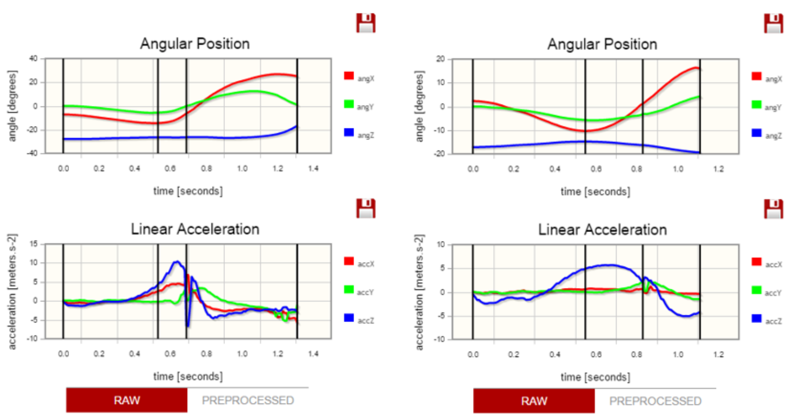



*FIGURE 4.* **ANGULAR POSITION AND LINEAR ACCELERATION: RAW DATA**

In Figures 4 and 5, Player 1 presents a small backswing and large follow-through, while Player 2 has a regular movement (almost a perfect sinusoid).

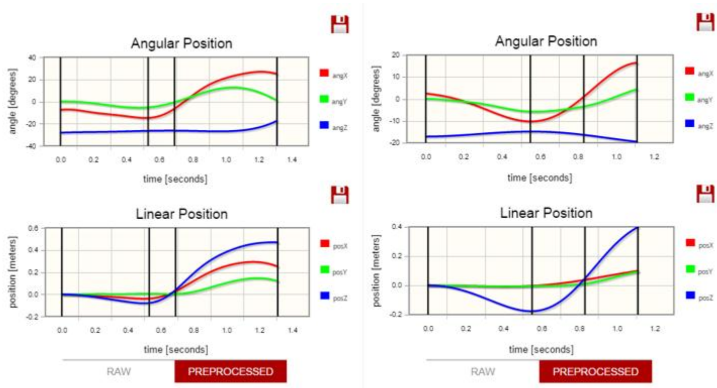
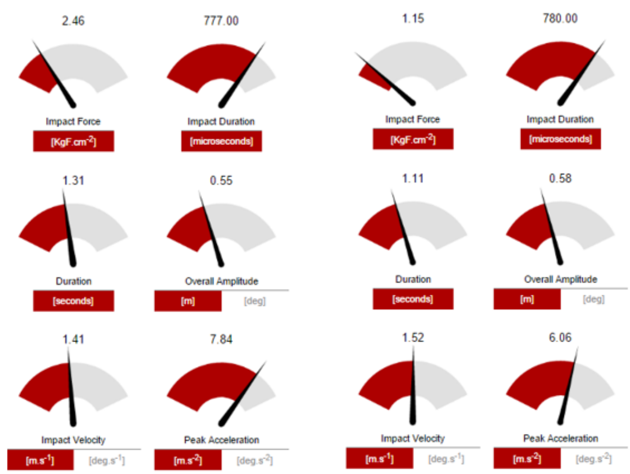



*FIGURE 5.* **ANGULAR POSITION AND LINEAR ACCELERATION: PRE-PROCESSED DATA**

Figure 6 shows several measures, like impact force, impact duration, duration, overall amplitude, impact velocity and peak acceleration. Although players perform differently, it can be observed in this figure that the impact duration and the overall amplitude are similar. However, Player 1 presents a larger impact force.




Impact force= $KgF.cm^{-2}$ Impact duration= µs Overall amplitude= m or deg
Impact velocity= $m.s^{-1}$ or deg. $s^{-1}$ Peak acceleration= $m.s^{-2}$ or $deg^{-2}$

*FIGURE 6.* **VALUES OF IMPACT FORCE, IMPACT DURATION, OVERALL AMPLITUDE, IMPACT VELOCITY AND PEAK ACCELERATION**

Figure 7 depicts the face angle. Although Player 2 is regular in terms of motion as observed in Figures 4 and 5, Player 1 presents a more accurate face angle (near zero degrees), which may be closely related to the fact that he also applied a smaller backswing.

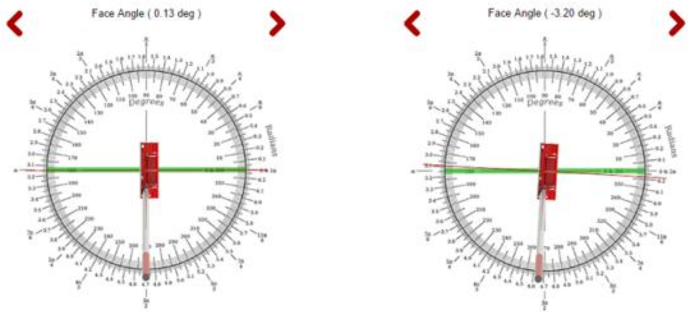



*FIGURE 7.* **FACE ANGLE (deg)**

As opposed to what was seen in the previous figure, Player 2 presented a declination angle that is considered more regular than the one presented by Player 1 (Figure 8).

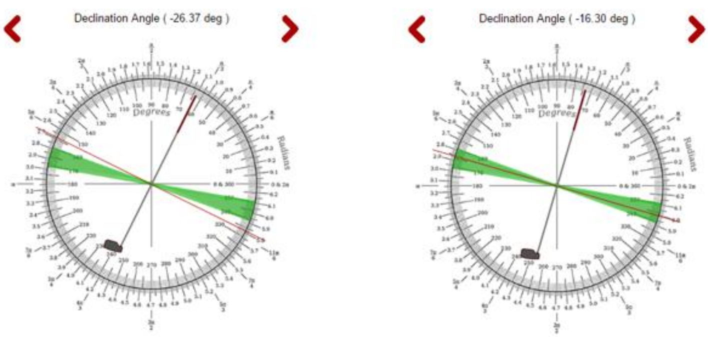



*FIGURE 8.* **DECLINATION ANGLE (deg)**

Figure 9 illustrates the position where the ball hit the face of the golf club during impact. It can be observed that, although both players seemed regular in this sense, Player 2 was able to hit the ball with the middle of the golf putter's face.

*FIGURE 9.* **IMPACT ON BALL WITH FACE OF PUTTER**

Finally, on analysing Figure 10, it was verified that both players presented a high heart rate. This could be ascribed to the succession of 90 putting trials they had to perform. Note that the green line in Figure 10 represents the heartbeat, wherein the R-R intervals can be observed.

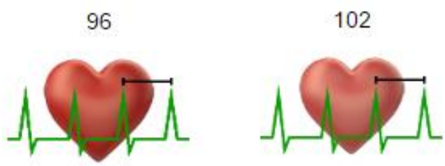



*FIGURE 10.* **HEART RATE (beat.$m^{-1}$)**

Although there was a difference in the heartbeat of the 2 players, the difference was not significant and it can be considered fairly stable for the last 5 beats, as a different R-R interval with the naked eye (distance between peaks) cannot be observed.

## DISCUSSION

The aim of this article was to show the innovative technology and science behind InPutter. The engineered putter allows one to measure all aspects of a putting stroke with high precision. In simple terms, golf putting can be learned in many different ways and by following many different methods (Couceiro *et al*., 2013a; Dias & Couceiro, 2015). Nevertheless, the individual variability underlying human motor behaviour makes this movement quite different from player to player, since the morphological and functional characteristics are distinct (Delay *et al*., 1997; Pelz, 2000). Additionally, the environmental context and other constraints (distance to the hole, number of people assisting the game, performance of opposing players, etc.), have a significant effect on the performance of a player (Dias *et al*., 2014).

All these factors have a decisive influence on how the golfer will hit the ball and adjust its action, namely the angular displacement of the putter, face and declination angles, applied force and all other process variables related with the motor execution (Sim & Kim, 2010). Moreover, golf putting also encompasses other relevant variables within the performance context, such as stability, routine, attitude and rhythm, as well as other aspects of personality, learning ability and motivation of players in the execution of this movement. One way to promote this consists on acquiring data about the motor performance and analyse it to identify and correct any technical inconsistencies (Dias & Couceiro, 2015). Although this can be done with cameras and other putting-specific devices available on the market, nothing can do it as well as the InPutter, as it maintains the ecological validity of the overall set-up, without additionally constraining the golfer with unrealistic situations (laboratory set-up, full-body suit, carrying additional equipment, among others).

## PRACTICAL APPLICATION

InPutter is an engineered golf putter designed for research, analysis and training purposes. By benefiting from an internal IMU sensor and wireless technology, it is able to retrieve the most relevant golf putting process variables, namely the putter's trajectory over time, velocity, duration and amplitude of each phase, as well as the impact force on the ball. As InPutter does not require any camera systems, markers, or system infrastructure, and given its robustness, weight and design as any other traditional golf putter, it can be used in both indoor and outdoor environments (Dias *et al*., 2014). Additionally, InPutter is an Internet-connected product that automatically connects to a cloud, thus allowing real-time debugging and monitoring over the Internet.

When compared with other products (Sam Puttlab), InPutter presents several advantages, such as it can measure heart rate and it is able to show a wide range of relevant golf putting process variables that other solutions cannot, namely the inclination angle, impact duration, impact force, follow through duration and follow through amplitude. Now, one can say that InPutter is the most complete engineered golf putter on the market.

## CONCLUSIONS

The preliminary experimental evaluation showed that the data retrieved using InPutter is in line with the current state-of-the-art tools, namely with the multiple scientific works published by the authors behind the development of InPutter. Furthermore, InPutter offers a wider range of variables when compared to the alternatives, from which one may highlight the golfer’s heart rate immediately before and during the putting, the impact force, duration and location where the ball hits the face of the putter, the mathematical kinematical model and 3D visualisation. Looking to the future, it is intended to validate the InPutter and benchmark it with other similar technologies.

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