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**Original Research**

# Electronic Training Instrument for Taekwondo Athletes

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**ABSTRACT**

This paper presents an electronic training instrument for taekwondo athletes. The proposed prototype was inspired by the electronic body protector (EBP) used in previous Olympic games. Besides counting points, our prototype measures the energy of each strike, providing information to coaches about every strike's force and location in real-time. The prototype consists of a transmitter module installed inside a chest protector, a receptor module, and a human-machine interface (HMI). The proposed prototype aims to provide coaches and athletes with a tool for monitoring and improving the taekwondo technique.

**Keywords**: Martial arts, electronic scoring system, sports technology, mechanical electronic protective pad

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## INTRODUCTION

Taekwondo is a Korean martial art performed with hands and feet. It is also a fighting sport because athletes use counterattacks and defensive techniques against their opponents. Taekwondo (TKD) is a martial art incorporated since the 2000 Sydney Olympic Games. TKD Olympic competitions include high and low-intensity body movements with short recovery periods [1]. In a typical Taekwondo game, athletes apply repetitive defensive and offensive kinetic patterns that require muscle precision strength, and power [2, 3].

Monitoring punches and kicks in actual game conditions is essential to improve the athlete's technique [4]. Researchers use several tests and instruments to measure performance in sports [5]. Many tests include contact mats, accelerometers, force plates, and video analysis. For example, in martial arts, estimation of kick forces is generally done using a 3D accelerometer, airbag force transducers, and kinematic analysis. However, although these tools provide accurate evaluations in a laboratory, their cost and lack of portability limit their application. As a result, several body wearable sensor systems capable have been developed. Wearable computing devices have become critical for humane machine interaction research [4, 5]. Attempts in artificial bioinspired e-skin can detect the direction of applied pressure for robotics [6]. Applications of wearable sensors as soft materials with sensor integration have applications in the healthcare field [7].

Different approaches use an inertial sensor for sports science and applications [8, 9]. For impact processing, wearing electronic prototype allows performance and tracking in football applications [10].

These devices only measure impact in absolute international system units (SI), such as Joules or the manufacturer's proprietary units [11]. Approaches as [12, 13] provide processing for valid score determination in measuring prototypes.

An official electronic body protector (EBP) adopted by the World Taekwondo Federation (WTF) must be able to record a valid impact with the appropriate sensitivity for each category. It is also crucial to receive immediate responses from the system for an objective evaluation of the athlete. All sports have various analytical methods to obtain qualitative and quantitative data to monitor the performance of athletes [14]. Performance monitoring is easier for individual sports than for team sports. The physical performance tests are the best to monitor the athletes' state and verify the effectiveness of training [15] and the minimum standards of the physical condition [16]. As well for the validity and reliability of linear positional measure the intensity of punch characteristics [17] and measuring the striking technique using an automation classification [18].

Taekwondo competition has critical limitations, such as achieving an accurate score validation and avoiding subjective judgment. A valid kick and punch must be precise and robust on the designated body part. The subjectivity of the evaluation criteria impeded the development of sports, which has resulted in the accusation of partial judges who favor certain players. There is extensive research [] to improve athletes playing conditions, but research on personal protective equipment (PPE) is lacking. One limitation is the energy absorption of the protective pad used to evaluate the PPE performance [19]. Uncertainty in point validation prompted the WTF to support the design of EBP that provide reliable and accurate score validation.

Some systems allow sensitivity adjustment according to the athlete's weight category [20]. In addition, the scoring system adopted in conjunction with the electronic body protectors contributes significantly to the improvement of precise techniques and skills. Sensor-equipped electronic body protectors allow accurate and reliable scoring providing coaches and athletes with the opportunity to develop competition strategies [21].

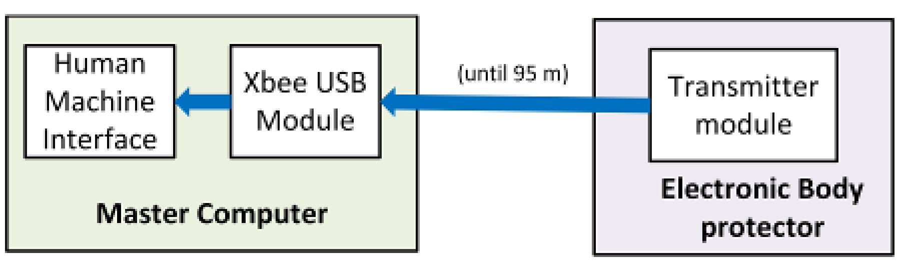



**Figure 1**. Taekwondo training module operation diagram.

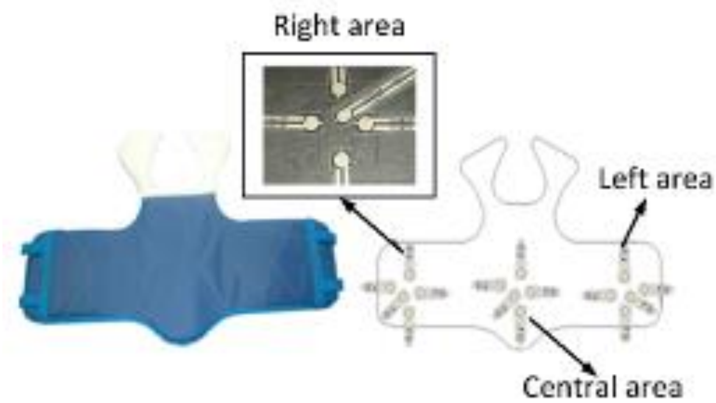



**Figure 2.** Distribution of the sensors inside of chest protector.

Understanding the benefits and limitations of the EBP, we proposed a prototype using the same EBP concept [22]. However, instead of only counting valid or invalid points, we include a flexible piezoresistive sensor Flexiforce A201, manufactured by Tekscan, Inc (Boston, MA, USA) [23] to detect the amount of force that reaches a competitor's body protector and transmits it to a master computer that processes and scores every kick. The proposed prototype is entirely wireless, which allows the athletes to use the prototype during static or dynamic training sessions with real-time response. Figure 1 shows the schematic of the proposed prototype.

## MATERIAL AND METHODS

### Prototype Design

We divided the prototype design into two phases: first, we designed and installed the transmitter into the body protector. Second, we chose the receptor and designed the human-machine interface (HMI) for the master computer. The HMI allows the user to monitor every impact location and measures its intensity in real-time.

*A. Transmitter module*

We used a piezoresistive sensor Flexiforce. The sensors were distributed into three matrices, and each matrix is composed of five sensors. The matrices are over the protective sponge, and the sponge is inside a chest protector. Figure 2 shows the distribution of the sensor. The signal generated by the sensors needs to be amplified to a low impedance signal. We employed an amplification signal circuit provided by the manufacturer, as it shows the Figure 3.

After the signal was conditioned, the output signal is connected to a microcontroller connected to the Xbee transmitter [24]. To obtain the optimal transmitter size, we propose a design based on minimal power consumption. The transmitter module is equipped with a microcontroller Atmega 8 [25] to collect the information from three sensor matrices. The main reason of the selected microcontroller has a processing velocity of 16 MHz and low power consumption.

Finding the proper position for the transmitter was critical. If the transmitter has an inappropriate location, the transmitter could be affected by any athlete's impact, affecting the transmission response or provoke discomfort on the athlete during the training session. The transmitter module was installed inside a taekwondo chest protector. The chest protector can be mounted on a standing kicking bag or another athlete during a training session. Figure 4 (a) shows the transmitter and the power supply. The transmitter module uses two 9Vcc batteries, the batteries were installed on the left side of the chest protector, and the transmitter module was located on the right side of the chest protector, as shown in Figure 4 (b).

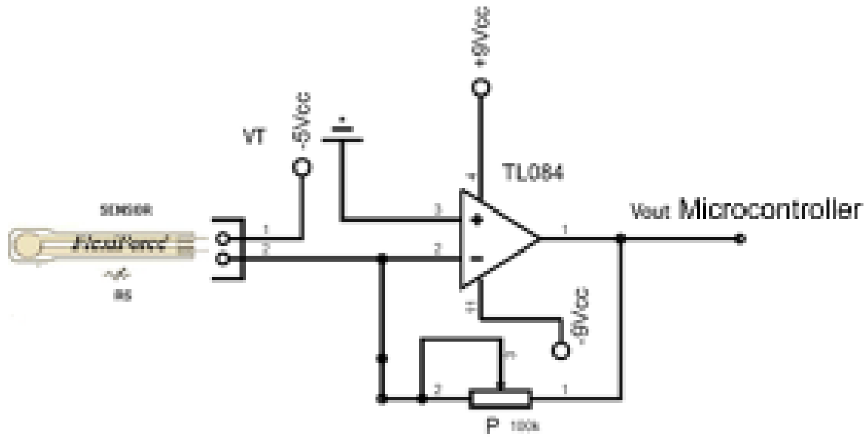
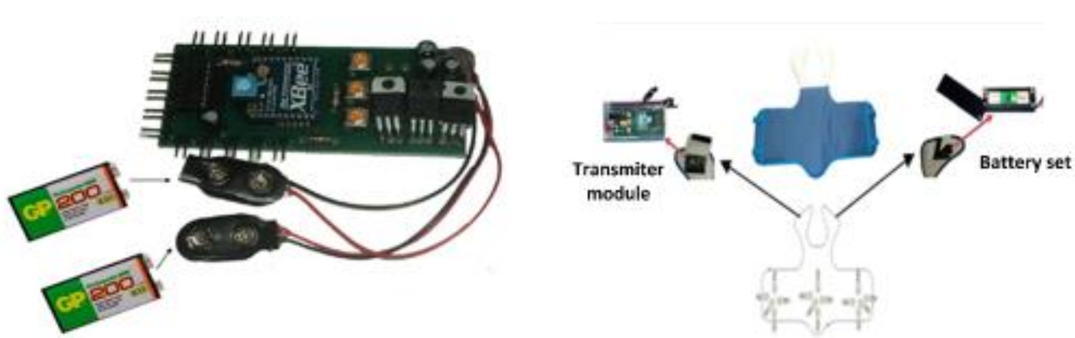



**Figure 3.** Amplification circuit for Flexiforce sensor.

*B. The Receptor module and HMI*

As a receptor, we used a USB-Xbee module connected to a master computer. We programmed a human-machine interface (HMI) to display all the information proceeding from the sensors mounted on the chest protector. For accurate scoring and monitoring, the signal processing should be in real-time. We used a distributed signal processing which allows us to process every signal individually and simultaneously. The master computer interprets these signals and updates the training collected data. The user can be supervised and save all the processed data. The HMI was implemented using LABVIEW. To initialize the HMI, the user has to set the practice time and choose the category, as shown in Figure 5 (c). The category depends on the athlete´s weight (fin, fly, bantam, feather, light, welter, light welter, light middle, middle, light heavy, heavy) given by the World Taekwondo Federation (WTF).
The prototype determines the standard force required for each impact and sorts them into valid or invalid points.After the training time is up, the HMI displays two plots, as shown in Figure 5 (d). The prototype has default values for sorting the impacts, the default minimum force is given in linear increment of 0.5 kilogram-force (Kgf) from 1 to 5.5 Kgf. For example, for the Finn category, the default force is 1Kgf. However, the minimum force values are arbitrary. The minimum force has to be set accordingly with the athlete or coach's preferences.
After the training time is up, the HMI displays two plots, as shown in Figure 5 (d). The plot on the right allows the user to load data from previous training sessions. The plot on the left shows the data for the current training session. The two plots provide the user with an interactive way to compare the evolution of the training. The HMI was designed for Spanish speaker’s users due that Figure 5 shows the captions with English subtitles.




(a) [b]

**Figure 4.** Transmitter module. [a] Transmitter module and Power supply. [b] Transmitter module and battery set installed inside of the body protector.

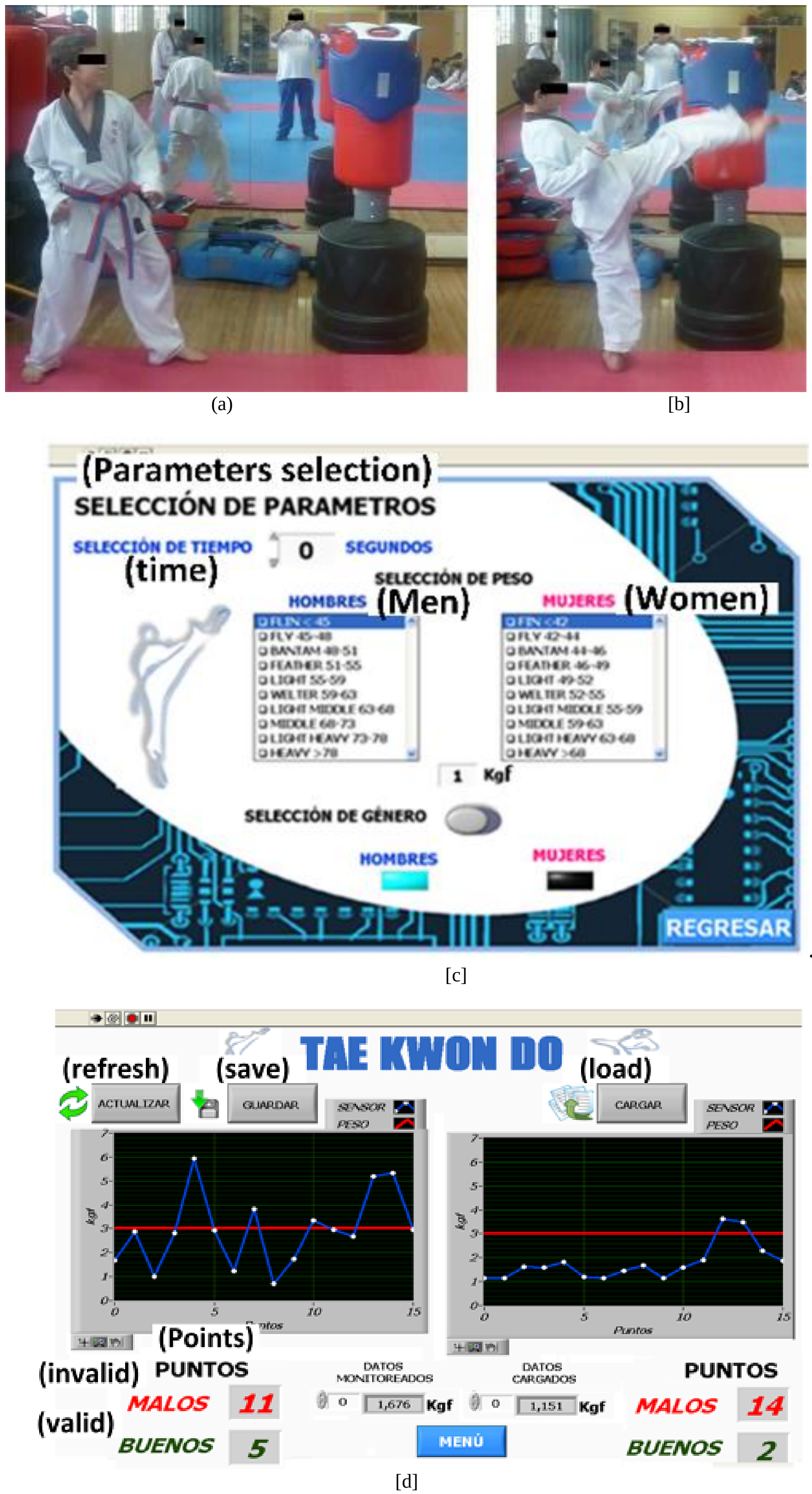



**Figure 5.** Training Station Kicking test. [a] Training station mounted on standing kicking bag. [b] Athlete kicking the training station. [c] Parameter selection window and [d] Summary of training session data window.

## RESULTS

Four subjects participated in this pilot study. Each subject is from different weight divisions: two males and two female athletes. The prototype was mounted on a standing kicking bag to collect the testing data, as shown in Figure 5 (a) and (b). Various kicking techniques were tested, including spinning kick, forward kick, backward kicks, front-hand and rear-hand punches. The test was performed in a local taekwondo center of Latacunga (Ecuador).

The athletes also aid to verify the response from the different prototype regions while a taekwondo coach assisted in counting the number of impacts. To validate the response of the training station, we started using standard weights to measure the prototype´s output, and we compared versus FlexiForce sensor values as ground truth. The weights range was from 0.75, 1-5.5Kg with intervals of 0.5 Kg. The full time of connection is 10.6 seconds. Table 1 shows the results using the voltage references.

The highest error is 2.78 %, and the lowest is 0.68%. The manufacturer recommend to calibrate the sensor using the voltage output. To proceed with the calibration, we applied the know force to the sensor and adequate the sensor resistance output to this force. Since the calibration values are based on the Force versus Conductance (1/R), we used voltage as output with a linear interpolation between zero load and the know loads. As additional validation, we perform a repetitive test, where we check the response of our system under several impact repetitions.

**Table 1.** Training station response versus ground truth values. The highest and lowest values are denoted in bold.

| Weight [Kg] | Output Voltaje [V] | Reference Voltaje [V] | Error [V] | Error [%] |
|---|---|---|---|---|
| 0,75 | 0,23 | 0,24 | 0,006 | 2,56 |
| 1 | 0,32 | 0,33 | 0,006 | 1,85 |
| 1,5 | 0,53 | 0,54 | 0,008 | 1,50 |
| 2 | 0,66 | 0,65 | 0,01 | 1,52 |
| 2,5 | 0,81 | 0,79 | 0,02 | 2,47 |
| 3 | 0,98 | 1,00 | 0,02 | 2,04 |
| 3,5 | 1,08 | 1,11 | 0,03 | **2,78** |
| 4 | 1,34 | 1,32 | 0,02 | 1,49 |
| 4,5 | 1,48 | 1,47 | 0,01 | **0,68** |
| 5 | 1,65 | 1,67 | 0,02 | 1,21 |
| 5,5 | 1,79 | 1,77 | 0,02 | 1,12 |

**Table 2.** Training station repeatability test. The highest and lowest values are denoted in bold.

| Weight [Kg] | Ref. Values | Test 1 | Test 2 | Test 3 | Test 4 | Test 5 | Total | Error [V] | Error [%] |
|---|---|---|---|---|---|---|---|---|---|
| 0,75 | 0,24 | 0,23 | 0,23 | 0,24 | 0,23 | 0,22 | 0,23 | 0,005 | 2,23 |
| 1 | 0,33 | 0,32 | 0,34 | 0,33 | 0,29 | 0,32 | 0,32 | 0,006 | 1,98 |
| 1,5 | 0,54 | 0,53 | 0,55 | 0,52 | 0,51 | 0,53 | 0,52 | 0,01 | 1,93 |
| 2 | 0,65 | 0,65 | 0,66 | 0,67 | 0,66 | 0,67 | 0,66 | 0,02 | 2,46 |
| 2,5 | 0,79 | 0,81 | 0,80 | 0,82 | 0,82 | 0,81 | 0,81 | 0,02 | 2,41 |
| 3 | 1,00 | 0,98 | 0,99 | 0,98 | 0,97 | 1,01 | 0,98 | 0,01 | 1,42 |
| 3,5 | 1,11 | 1,08 | 1,07 | 1,09 | 1,09 | 1,08 | 1,08 | 0,03 | 2,45 |
| 4 | 1,32 | 1,34 | 1,33 | 1,34 | 1,33 | 1,35 | 1,33 | 0,02 | 1,35 |
| 4,5 | 1,47 | 1,48 | 1,49 | 1,47 | 1,48 | 1,49 | 1,48 | 0,01 | 0,81 |
| 5 | 1,67 | 1,65 | 1,65 | 1,64 | 1,67 | 1,65 | 1,65 | 0,02 | 1,02 |
| 5,5 | 1,77 | 1,79 | 1,80 | 1,80 | 1,78 | 1,79 | 1,79 | 0,02 | 1,23 |

Table 2 shows five different tests with the highest error of 2.46%, and the lowest is the lowest, which is 0.81%. For collecting the values shown in the Tables 1 and 2, the systems were calibrated under the international metric system (SI) following the sensor manufacturer recommendation. The propective sponge was included in the calibration process. In addition, the Cronbach's alpha value is $\alpha = 0.93$ which indicates an excellent consistency for the repeatability test.

## CONCLUSIONS

Inspired by the Olympic taekwondo EBP, the proposed prototype allows measuring the intensity of every impact and classifying them into valid or invalid points, depending on the athlete's weight. The proposed electronic training station provides an alternative to enhance the training of amateur taekwondo athletes. Our prototype allows the measurement of valid and invalid points given the athlete or coach´s preferences. In addition, the HMI allows the user to monitor and save the progress of every training session. As future work, the prototype will be enhanced, including even more data about combat techniques and real-time data procession based on deep learning to determine the optimal athlete performance.

**Author Contributions:** Conceptualization, VR-C. and RS.; methodology, VR-C. and RS.; formal analysis, MS. and FS.; investigation, VR-C and RS.; resources, RS.; data curation, RS.; writing—original draft preparation, VR-C. and RS.; writing—review and editing, V-RC.; supervision, MS. and FS-.; project administration, RS. All authors have read and agreed to the published version of the manuscript.

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**Institutional Review Board Statement**: The study protocol was approved by the local ethics committee of the Federacion Deportiva de Cotopaxi (Latacunga – Ecuador).

**Informed Consent Statement:** Informed consent was obtained from all subjects involved in the study.

**Data Availability Statement:** Data will be available at request.

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## References

1. Matsushigue KA, Hartmann K, Franchini E. Taekwondo: Physiological responses and match analysis. The Journal of Strength & Conditioning Research. 2009;23(4):1112-7.
2. Pieter W, Heijmans J. Scientific Coaching for Olympic Taekwondo, Meyer & Meyer Sport. Oxford, UK; 2000.
3. Serina E, Lieu D. Thoracic injury potential of basic competition taekwondo kicks. Journal of biomechanics. 1991;24(10):951-60.
4. Zhang C, Liu S, Huang X, Guo W, Li Y, Wu H. A stretchable dual-mode sensor array for multifunctional robotic electronic skin. Nano Energy. 2019;62:164-70.
5. He Z, Chen W, Liang B, Liu C, Yang L, Lu D, et al. Capacitive Pressure Sensor with High Sensitivity and Fast Response to Dynamic Interaction Based on Graphene and Porous Nylon Networks. ACS Applied Materials & Interfaces. 2018;10(15):12816-23.

6. Boutry Clementine M, Negre M, Jorda M, Vardoulis O, Chortos A, Khatib O, et al. A hierarchically patterned, bioinspired e-skin able to detect the direction of applied pressure for robotics. Science Robotics. 2018;3(24):eaau6914.
7. Lim H-R, Kim HS, Qazi R, Kwon Y-T, Jeong J-W, Yeo W-H. Advanced Soft Materials, Sensor Integrations, and Applications of Wearable Flexible Hybrid Electronics in Healthcare, Energy, and Environment. Advanced Materials. 2020;32(15):1901924.
8. Espinosa HG, Lee J, James DA. The inertial sensor: a base platform for wider adoption in sports science applications. Journal of Fitness Research. 2015;4(1):13-20
9. Worsey MTO, Pahl R, Thiel DV, Milburn PD. A Comparison of Computational Methods to Determine Intrastroke Velocity in Swimming Using IMUs. IEEE Sensors Letters. 2018;2(1):1-4.
10. Dunn M, Hart J, James D. Wearing Electronic Performance and Tracking System Devices in Association Football: Potential Injury Scenarios and Associated Impact Energies. Proceedings. 2018;2(6):232
11. Song Y, Jeon Y, Park G, An H, Hwang T, Lee H, et al. Development of taekwondo trainer system for training on electronic protector with hitting target indicator. International Journal of Computer Science and Network Security. 2010;10(6):51-6.
12. Krajewski A, Helmer R, Lucas S. Signal processing for valid score determination in amateur boxing. Procedia Engineering. 2011;13:481-6.
13. Buśko K, Staniak Z, Szark-Eckardt M, Nikolaidis PT, Mazur-Różycka J, Łach P, et al. Measuring the force of punches and kicks among combat sport athletes using a modified punching bag with an embedded accelerometer.2016;18:1. [1509-409X [Print]].
14. Bayraktar B, Kurtoğlu M. Sporda performans, etkili faktörler, değerlendirilmesi ve artırılması. Klinik Gelişim. 2009;22(1):16-24.
15. Ball N, Nolan E, Wheeler K. Anthropometrical, physiological, and tracked power profiles of elite taekwondo athletes 9 weeks before the Olympic competition phase. The Journal of Strength & Conditioning Research. 2011;25(10):2752-63.
16. Marković G, Mišigoj-Duraković M, Trninić S. Fitness profile of elite Croatian female taekwondo athletes. Collegium antropologicum. 2005;29(1):93-9.
17. Lambert C, Beck BR, Weeks BK. Concurrent Validity and Reliability of a Linear Positional Transducer and an Accelerometer to Measure Punch Characteristics. The Journal of Strength & Conditioning Research. 2018;32(3):675-680.
18. Soekarjo KM, Orth D, Warmerdam E, Van Der Kamp J, editors. Automatic classification of strike techniques using limb trajectory data. International Workshop on Machine Learning and Data Mining for Sports Analytics; 2018: Springer:131-141.
19. Del Vecchio F, Franchini E, Del Vecchio A, Pieter W. Energy absorbed by electronic body protectors from kicks in a taekwondo competition. Biology of Sport. 2011;28(1):75.
20. Tasika N. Reliability & linearity of an electronic body protector employed in taekwondo games: a preliminary study. Journal of Human Sport and Exercise. 2013;8(3):S622-S32.
21. Leveaux R, editor Technology driving changes in competitor decision making and match management. Business Transformation through Innovation and Knowledge Management: An Academic Perspective-Proceedings of the 14th International Business Information Management Association Conference, IBIMA 2010:1.
22. Rosas-Cervantes V, Achig E. Diseño e implementación de un prototipo peto electrónico para el monitoreo de golpes en competencia de taekwondo. 2011. Available online: https://repositorio.espe.edu.ec/bitstream/21000/4312/1/T-ESPEL-0818.pdf
23. Tekscan Inc. FlexiForce, Standard Force & Load Sensors Model A201. Datasheet. Available online: https://www.tekscan.com/sites/default/files/resources/FLX-A201-A.pdf.
24. Digi International. Digi XBee, Wireless connectivity module, Model PRO OEM RF 2.4 GHz. Available from: https://www.digi.com/resources/documentation/digidocs/pdfs/90000991.pdf.
25. ATMEL. Low-power Atmel AVR 8-bit Microcontroller.