Development of a Real-Time Evaluation System For Top Taekwondo Athletes

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***Abstract* - At any level of sport, evaluating the performance of the athletes is a constant challenge for trainers. In the case of Taekwondo, where there is lack of technological solutions to help the trainer to perform this task, there is a higher difficulty. The system presented in this paper is part of a PhD project, which the main objective is to develop a system reliable and affordable for evaluate in real-time the performance of top Taekwondo athletes. The system consists of a 3D camera Orbbec Astra with RGB and depth sensor and a computer for data acquisition and processing. The data (information of the Cartesian coordinates and speed of the hands and feet movements performed by the athlete) is displayed in real-time either by numerical value or by charts. It is intended to provide an accurate feedback for the correction or improvement of the athlete's technique, allowing an increase in the athlete performance in a shorter period of time. Aiming to evolve the Taekwondo training techniques and the technological development of Taekwondo practice.**

Keywords - motion analysis; orbbec astra; performance; real-time; Taekwondo.

I. INTRODUCTION

In today's society, technology has been assimilated as something natural and accessible, being part of the daily routines. The regular use of technology, in the personal, professional and even during the educational journey, comes from the combination of information processing with objects. This combination provides a reality where the extension of computing devices into in everyday life is known as "Ubiquitous Computing" [1]. Ubiquitous computing has been suffering a fast-growing with applications in many areas.

One of these areas is motion analysis where there has been active participation of scientists in the development of technological solutions that do not require markers on the human body for monitor and analyze athletes' movements performed in ordinary environment conditions. The use of these new methods of movement analysis have contributed to for the emergence of motion capture solutions and low-cost and accessible equipment [2].

One of the applications is in sports, where the equipment are used not only to collect, analyze and present athletes performance data from training practices and competitions but also to develop automatic score and refereeing systems [3]. This trend allows the development of athlete's performance feedback systems, by measuring accelerations and forces, recognizing and tracking movements, quantifying the effort applied and many other functionalities. The overall objective is to reduce the time of analysis of the trainer and to accelerate the improvement of the performance of the athlete [4] [5].

Taekwondo was introduced in Portugal in 1974 by Grand Master David Chung Sun Yong [6]. Over the last two decades, it has gained popularity and it became an Olympic Sport in the year 2000 [7]. The number of federated athletes has been increasing, reaching currently more than 4500 athletes in Portugal [8]. Unlike other sports, Taekwondo has not accompanied the technological development regarding training methods. Nowadays, the evaluation methods used by the trainers are mostly made manually, making the assessment of the athletes a slow, and sometimes, inefficient process. The trainer has to analyze all the available data, such as videos, time and number of movements' executions, in order to obtain the information needed to provide a relevant feedback that allows the athletes to improve their performance.

Martial arts and combat sports depend on special activities that expect complex skills and tactical excellence. The movements most executed by the athletes consist of specific stances and dynamic activities (strikes, punches, kicks, throws, blocks, falls, among others) performed individually or in contact with the opponent. The majority of

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them are characterized by high dynamics, high intensity and very short duration, usually named as ballistic movements [9].

Following this trend, the main objective of the present work is to develop a real-time system to evaluate the performance of the Taekwondo athletes in training environment, taking into account reliability, usability and the cost of the system. The proposed system aims to provide a faster feedback process, contribute to an evolution of the performance of the most effective athlete and add technological development in the practice of taekwondo. This study presents the system structure and the developed software, which allows input data of the athletes training and output data of the Cartesian coordinates and speed of both hands and feet.

This paper is divided in five sections. The Section 2 addresses the state of the art in the field of motion analysis and performance evaluation in sports. The Section 3 presents the methodology used for the development of the technological tool to aid the evaluation of athletes in real time. In Section 4 are disclosed the final remarks of the development process and of the achieved system. The Section 5 reveal the future work regarding the further development and application of the system presented in this paper.

II. State of Art

Motion analysis, over time, has aroused the interest of several areas of scientific research. With the evolution of technology, several devices have emerged that enable the monitoring and analysis of movements performed by the human body. Sports area currently represents a significant part of the research conducted with the aim of contributing to both improving athletes' performance and preventing injury.

For trainers, motion analysis has been a key issue as it can improve technical skills by correcting the trainee's body motion to perform correct movements in any sports.

Some of the research carried out in motion movement aims to study the hands movements and localization, such as the study of Suarez and Murphy [10] that consists in a survey where they resumed the techniques used for hand localization and gesture classification.

Traditional video cameras, when used in low or in unstable lighting and in skin colored objects environments, hamper the correct digital analysis of the image. The depth cameras are the appropriate alternative for image collection in these situations, as they allow to collect depth images that are not dependent on the brightness or color scheme of the environment. The most used depth sensor in scientific research regarding hand localization and gesture classification is the Microsoft Kinect [10]. Microsoft Kinect systems are low cost, portable, do not require markers, are easy to set up, and create 3D images. These 3D video motion systems are used to human movement kinematics analysis of body joints and segments in several areas associated with gait analysis, medical robotics, rehabilitation, biofeedback and sports performance.

Concerning the whole human body gesture recognition Patsadu, Nukoolkit and Watanapa [11] present a study for human gesture recognition using data mining classification methods in video streaming of twenty body-joints positions of the human body collected with the Microsoft Kinect camera. The study recognized gesture patterns as stand, sit down, and lie down. The classification methods adopted for comparison were backpropagation neural network, decision tree, support vector machine and naive Bayes. For this, the researchers used the Microsoft Kinect camera. The results obtained allowed to conclude that backpropagation neural network shows superior performance compared to the other classification methods, recognizing human gestures with 100% accuracy. The average accuracy of all classification methods was 93.72%, confirming the efficiency of the Kinect camera when used in human body recognition applications.

Other study of the Microsoft Kinect was performed by Zerpa et al. [12]. They compared the Microsoft Kinect displacement measures with the Peak Motus marker-based system displacement measures. The results allowed to conclude that the Microsoft Kinect, for being a markless system, was more favorable during the setup, data collection and analysis stages as compared to the Peak Motus.

In their study, VencesBrito et al. describe and compare the variety of modern motion analysis systems used in scientific research as well in the daily work of coaches and athletes in combat sports and martial arts. The authors suggest some applications in scientific research and scope of applications that contribute for optimizing the training process, providing information for non-expert trainers and athletes in the field of biomechanics but interested in motion analysis [13].

Pinto et al. [14] present a real-time evaluation approach that uses a Microsoft Kinect and image processing techniques to recognize and record the number of occurrences of a movement in Taekwondo training environment. The recognition of the movements was made through the calculation of the angles between human body joints and comparing them with the correct values of each movement previously saved in a database.

Further studies are needed, to confirm the reliability and validity of the Microsoft Kinect for human movement kinematics analysis [12]. However Robertson et al. [15] and Corazza et al. [16] both verified and agreed that markerless systems would be a major revolution in the analysis of human motion and significantly would expand the application of human motion capture.

III. Development

The training process in martial arts, just as in other sports, aims to improve the performance of certain techniques and strategic behaviors along with the increase of the physical condition of the athlete, allowing him/her to compete with other athletes and reduce the risk of injury. The analysis of the movements performed by the athletes is a key element in training sessions. In this sense, motion analysis could provide relevant information about the accuracy of the athlete techniques and identify errors, when implemented during the training. The information collected

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should serve to apply actions that allow the trainers and the athletes to correct the errors and adjust the training plan. Thus, contributing to improve the efficiency of movements and obtain the expected progress [13].

The study exposed in this paper is part of a PhD project, which has the main objective to develop a system where the overall goal is the evaluation of performance of top Taekwondo athletes in real time.

The system developed consists in a 3D camera with RGB and depth sensor, a computer and a software for data processing and storage, as seen in Figure 1. It is intended that the developed system is as portable and easy to use as possible, without neglecting the reliability and robustness.

Figure 1. Sperta system architecture

It is provided a graphical environment for the user to interact with the system that allows:

- the trainer to enter the athlete information and training data;
- to store the training data in a database;
- real-time visualization of movements and joints of the athlete;
- view through charts the Cartesian coordinates values of the athlete's hands and feet;
- graphical visualization of the instantaneous velocity of the athlete's hands and feet.

The depth sensor chosen for the development of the system was the 3D camera Orbbec Astra, shown in Figure 2, that provides 640 pixels x 480 pixels at 30 frames per second for depth and RGB image size, a 0.6 to 8 meter range and a field of view of 60° horizontal x 49.5° vertical (73° diagonal). Another relevant aspect to the choice was the small size and ease of use that are important for the usability of the system. Thus, the dimensions of the Orbbec Astra are 165 x 30 x 40 mm, the weight is 300 grams and the power supply and the data interface only require a USB 2.0 port [17]. Comparing with Microsoft Kinect 2, the most used depth sensor in research, Orbbec is smaller, has less weight, with a higher maximum reach distance.

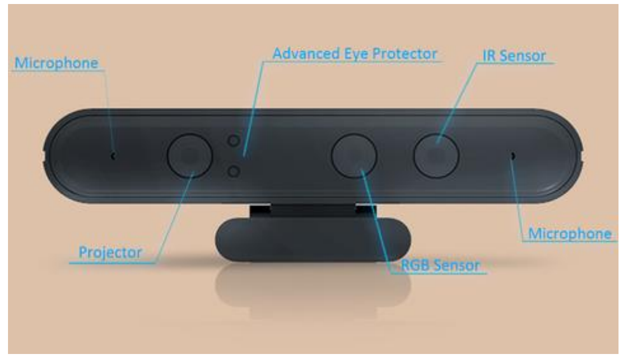

Figure 2. 3D Camera Orbbec Astra [17]

The performance of the computer must be taken into account for the proper functioning of the system. Due to the large amount of data read, processed and stored by the software, the performance of the computer is of utmost importance. The better the processing capacity is, the better the efficiency of the movements' data collection is, either by the motion sensor or by the software where the information is processed. The computer used for the development consists of a portable computer, with 4th generation Intel® Core ™ i7-4720HQ processor with Intel® Turbo Boost Technology 2.0, 8 GB of RAM, AMD Radeon ™ R9 M265X graphics card with 2 GB dedicated and Microsoft Windows 10 64-bit operating system.

A Windows application was developed, so that it can be used by computers running the Windows operating system, the most commonly used operating system in Portugal at the moment [18]. The programming language used was C# along the Microsoft Visual Studio 2017 IDE. Although Orbbec Astra provides a SDK with full body skeleton tracking, Orbbec itself advises the use of Nuitrack ™ that has been developed in partnership with 3DiVi Inc. Nuitrack™ is a 3D skeleton tracking gesture recognition solution middleware enabling Natural User Interface (NUI) capabilities on Android, Windows and Linux platforms [19].

The developed software interface consists of several windows/forms that allow the user to enter and view the information regarding the training performed, visible in Figure 3a). The main window has 3 buttons, one for 'Add athlete', one for 'Begin training', one for 'Exit' application and also fields for data entry of the training to be performed.

When pressed the 'Add athlete' button another window opens, Figure 3b), that allows adding the database athlete data such as name, age, weight, height, gender and team. The 'Begin training' button is pressed after selecting the athlete in the dropdown field ´Name:´, which automatically fills the remaining fields referring to the athlete.

After 'Begin training' is pressed, a new window opens, Figure 3c), that allows to see the depth image and the athlete hands and feet joints movements data in Cartesian coordinates numeric values, Cartesian coordinates line chart and speed line chart, all in real-time as presented in Figure 4.

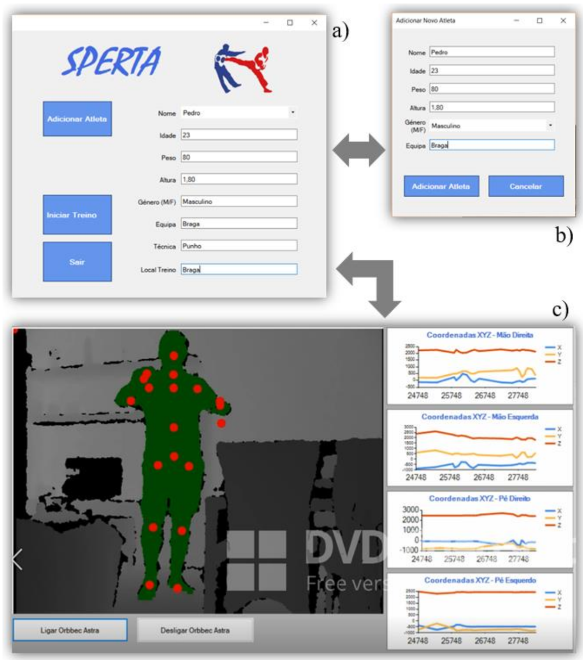

Figure 3. Sperta software interface windows: a) information regarding the training; b) athlete data; and c) depth image and line charts.

The joints Cartesian coordinates are obtained through the Nuitrack™ SDK integrated in the software and their values are presented in millimeters. The values of each one of the joints refer to the X, Y, and Z coordinates relative to the range of the 3D camera Orbbec Astra.

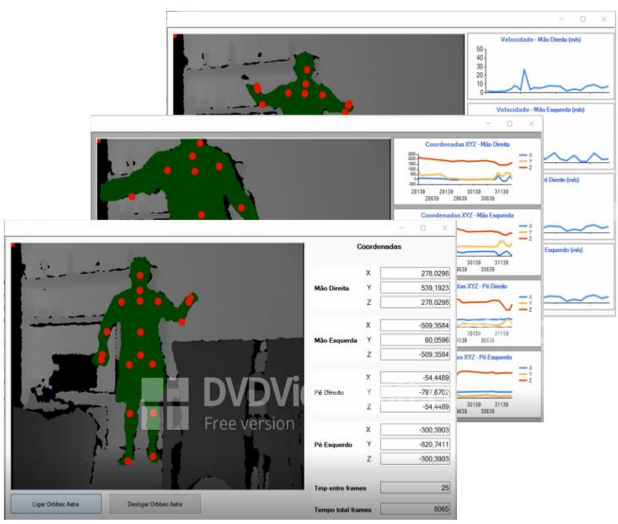

Figure 4. Depth sensor, cartesian coordinates and speed data output in real-time

It is important for the trainer to access the previous training information in order to evaluate the performance evolution of the trainee. The developed software integrates an SQL database where all the training data collected with the system is saved, which structure is presented in Figure 5.

The database is divided into three tables: 'Athlete' table with fields 'IdAthelete', 'name', 'age', 'weight', 'height', 'genre' and 'team'; 'Training' table with fields 'IdTraining', 'dateHour', 'technique, 'place' and foreign key 'trainingAthlete'; 'CoordinatesXYZ' table with fields 'IdCoordinates', 'time', 'handRightX', 'handRightY', 'handRightZ', 'handLeftX', 'handLeftY', 'handLeftZ', 'footRightX', 'footRightY', 'footRightZ', 'footLeftX', 'footLeftY', 'footLeftZ' and foreign key 'coordinatesTraining'.

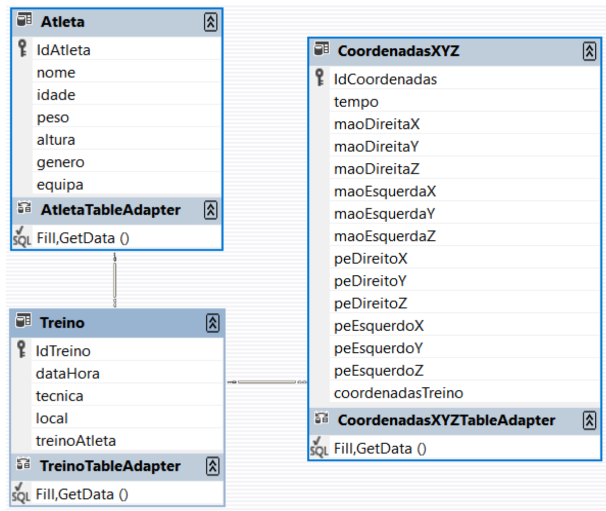

Figure 5. Database tables and data fields (in Portuguese).

The speed of the athlete joints movements is not obtained directly from the SDK Nuitrack. To calculate the speed of the athlete's movements in real-time using the Cartesian coordinates it is necessary to calculate the movement displacement value according to the time elapsed between each reading. For that it was used the distance equation in three-dimensional Euclidean space (1). Where p and q are the current values read and the last read antecedent's values, respectively of the Cartesian coordinates of the joints.

$$d(\mathbf{p},\mathbf{q}) = \sqrt{(p_1-q_1)^2+(p_2-q_2)^2+(p_3-q_3)^2} \qquad (1)$$

The time elapsed between two adjacent acquisitions was calculated (current coordinate data of the joints of the athlete and the previous coordinates). This calculation was performed through the used computer system clock in milliseconds (2), where t and t_{-1} are the current time value and the time value of the previous Cartesian coordinates read respectively.

$$te = t - t_{-1} \qquad (2)$$

After calculating the joints distance between the collected data and the time between data collection, the velocity calculation was performed using (3), where *ds* and *dt* are the derivative of the displacement value of the joint and the derivative of the value of the time elapsed between the displacement, respectively.

$$v = \frac{ds}{dt} \tag{3}$$

The calculated speed values are presented by the software in real-time allowing the trainer to follow the evolution of the training and providing relevant feedback in real-time to the athlete.

In order to verify the accuracy of the system developed, some tests were made, where the recording of the operation and data presented in real-time was performed. The collected (in the database) output graphs of various sections of the training were compared with the charts provided by the system software. The charts of the database were created using the Microsoft Excel worksheet. In Figure 6, it is possible to visualize the comparison between the Cartesian coordinates of the movement realized by the right hand during the period comprised between the 9890 and the 13895 milliseconds of a section of training.

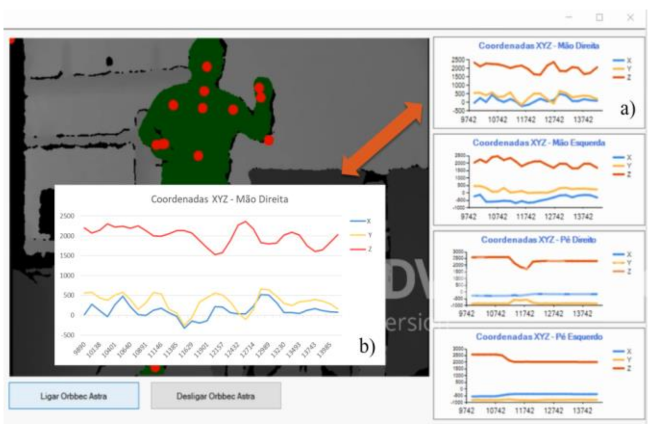

Figure 6. Hand right Cartesian coordinates charts from 9890 to 13895 milliseconds: a) Excel chart of values collected by Orbbec Astra and stored in the database; b) graph of the values presented by the software in real time.

This comparison seeks to visually verify that the values collected in real-time by the Orbbec Astra 3D camera, Figure 6 a), and the values presented by the software in real-time, Figure 6 b), are the same. This allows us to conclude that the system performance is effective and able to provide real-time feedback of the performance of Taekwondo athletes.

IV. Conclusion

The development of an accurate, economically affordable and non-invasive solution to monitor in real-time the practice of Taekwondo is of utmost importance [5].

The system presented in this paper intends to accomplish the performance evaluation of taekwondo athletes in real-time in a training environment. The evaluation of the movements of the athlete is performed through motion analysis of the movements, using computer processing of the information collected through the 3D Camera Orbbec Astra, with its depth sensor and the SDK Nuitrack™.

The system developed allows the trainer and athlete to have a real-time feedback of the movements performed during the training and the speed of the movement execution. In fact, the objective is to provide a tool that could be used by both, trainer and athlete, which promotes an increase in the speed of the feedback of the trainer on the performance of the athlete during the training.

Thus, the developed system aims to be an easy-to-use and affordable technology solution and to contribute to the technological development of the performance evaluation of Taekwondo athletes in a training environment.

V. Future Work

The system presented is part of a larger project and it is still under development. So, it is intended to add other features to the system, such as: output of the movements acceleration and strength in real-time, either in numeric values or charts; output of the speed, acceleration and strength of more human body joints relevant to the evaluation of the athlete performance; create a database with the correctly executed Taekwondo movements Cartesian coordinate’s patterns, for use as reference values; identify and count the movements performed by the athlete during the training sessions using deep learning methods, such as backpropagation neural network using as reference values the data previously saved in the database of the correct execution of the movements.

Finally, it will be necessary to test the software in real training environment with Taekwondo top athletes to be able to adjust the system to the real needs of the training, as well as collecting enough data to allow the use of deep learning methods needed to make the system more efficient and accurate in real-time interpretation of data.

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