AN AUTOMATED ATHLETE PERFORMANCE EVALUATION SYSTEM
From Theory to Practice

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Abstract: In order to obtain information on athletic performance, strength and power characteristics of the athlete are generally evaluated. However, due to the large number of variables needed for the assessment, this kind of evaluations is usually time consuming. Taking advantage of recent developments in the area of sensors and acquisition systems and using signal processing algorithms reported in the literature, we developed a new Athletic Performance Evaluation System. This system automatically determines evaluation parameters and integrates them in ready-made reports, decreasing the time involved in the evaluation process. The system is based on the installation of sensors and wireless acquisition systems at the assessment workstations of a Sports Evaluation Laboratory. At present, Jump Platform, Leg Press and Multipower workstations are being used. Strength and displacement data collected by the sensors at these workstations is automatically processed in real time at the Central Base Station where standard force and power related evaluation parameters are determined. Graphical representations of time evolution of the variables being measured by the sensors are showed in real time on the screen. Each evaluation session is defined by a protocol that can be specifically created by the coach for each athlete. The results of the evaluations are stored in an athletes' database so that the historic performance of the athlete can be easily assessed. The resulting system presents the deployment of sound theoretical evaluation metrics in a real time athlete performance evaluation system.

1 INTRODUCTION

Athletic performance can be assessed by analyzing specific variables that provide information about the physical condition of the athlete. Generally, strength and power related variables are the gold standard for athletic evaluation. For their assessment, specific tests and procedures are used (Morrow et al, 2005). Those tests are designed in accordance to recommendations and guidelines that assist coaches collecting valid and reliable data used to determine the needed evaluation parameters (Brown et al, 2001).

Traditionally, and according to the assessment guidelines, a large amount of evaluation variables must be determined in order to obtain complete information on the athlete's physical condition. Usually, the data measured during the evaluation tests is processed *a posteriori* and summarized in reports that are analyzed a few hours or even days after the tests are done, which also contributes to the slowness of the evaluation. With the recent technological advances, this situation can be overcame. Besides introducing new levels of objectivity, automation and usability into the evaluation process, the use of new technological tools may reduce markedly the time needed to complete a performance evaluation session. The training process itself is, nowadays, turning into a process that uses the advantages of new technologies (Liebermann et al, 2002): the use of sensors and real-time presentation of the athlete's signals during training provides athletes and coaches with sophisticated objective information about the sport performance evolution and it can also be used as a real time feedback tool.

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This paper describes a new Athletic Performance Evaluation System based on real-time measurement and processing of signals generated by the athlete during the assessment tests. Using wireless sensors and acquisition systems installed on different evaluation workstations, an athlete-focused system that includes automated algorithms for determining strength and power-related variables was developed. Standard evaluation methods (Hori et al, 2006, Linthorne et al, 2001; Dowling et al, 1993) used for manual analysis of data in the traditional evaluation laboratories were automated in order to obtain a faster, integrated evaluation system. In this way, the time involved in testing each athlete is decreased by a factor of three.

The computed variables are summarized in a ready-made report and may be used as performance indicators for purposes such as the quantification of the relative contribution of strength and power to athletics events, the identification of specific weaknesses and prescription of suitable training/rehabilitation programs, the follow-up of training/rehabilitation programs or even the identification of athletic talented individuals.

2 GENERAL DESCRIPTION

The setup of the system involves both hardware and software modules. Signal acquisition and transmission is done by wireless signal acquisition hardware and measurement sensors installed on the evaluation devices of the laboratory. Data analysis and reporting as well as management of athletes database and evaluation protocols are performed by the different software modules installed on a Central Base Station.

The system works on a workstation/protocol basis.

Each workstation is composed of an evaluation device instrumented with measurement sensors and a wireless acquisition unit which collects the signals measured by the sensors. The acquired data is transmitted in real time to a Central Base Station via Bluetooth, where it is automatically processed and represented on a screen. For the moment, three workstations are predefined: (a) Leg Press: for evaluation of force production characteristics of the lower members; (b) Jump Platform: for evaluation of reactive force of the inferior members and (c) Multipower: for evaluation of force production characteristics of the superior members and dynamic parameters such as power, velocity and muscular resistance (Figure 1).

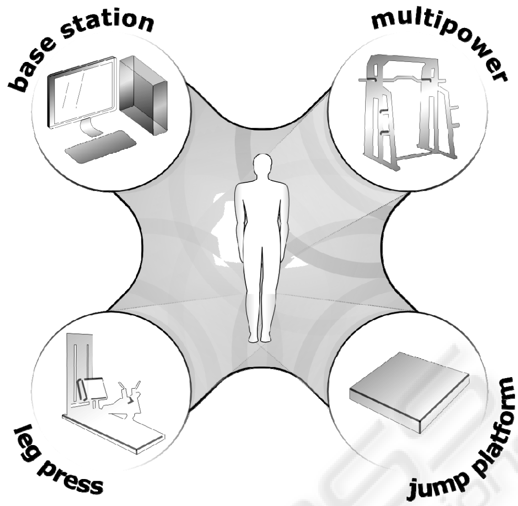

Figure 1: Schematic Representation of powerPlux athletic performance evaluation system setup.

Each evaluation session is defined by a protocol that is previously designed by the coach for the athlete. To build a protocol, the coach chooses the set and sequence of evaluations the athlete will execute as well as the respective details. In the end of each evaluation session a report is produced that summarizes it and presents the best results, allowing also the introduction of comments by the coach. If several sessions of a same evaluation protocol are performed, a comparative report may be produced.

Given the wireless connectivity between the workstations and the Central Base Station, the coach can easily follow the athlete's work, in three simple steps: (a) connect: communicate wirelessly with the workstation; (b) acquire: automatically access the main performance indicators in real-time; and (c) visualize: session and historic reporting and analysis, with graphical curves representation and gain indicators.

Simultaneously the athlete has real-time feedback about his/her performance during the evaluations, with automated visual and acoustic aids to support the protocol execution. The fact that this feedback information is given in real-time to the athlete provide conditions for him/her to improve significantly the process of skill acquisition and sport performance (Schmidt et al, 1999; Liebermann et al, 2002).

Besides the automated data acquisition, processing and analysis module, powerPlux also has a management module which includes an Athlete Database to store relevant information for each athlete, each evaluation session and corresponding final reports.

3 HARDWARE

The recent technological developments in the area of hardware design and integration offer appropriate tools for the development of compact, miniaturized and versatile systems with a large range of applications in the areas of real-time signal acquisition and processing (Silva *et al*, 2005).

At a Sports Evaluation Laboratory, space needs to be clear of obstacles and evaluation tools should not interfere with athletes' performance, so that parameters such as wireless connectivity, miniaturization, versatility and usability are desirable features when one thinks of a sports assessment tool. Taking advantage of the new acquisition hardware solutions (Silva *et al*, 2005), we developed powerPlux Athletic Evaluation System, which gathers the features referred above. Each Workstation is instrumented with a 12bit, 1000Hz bioPlux8 wireless acquisition system and suitable sensors for measuring the signals produced by the athlete at those workstations (Table 1). In this way, the analog data measured by the sensors are converted to digital data by the bioPlux8 uint that communicates via Bluetooth with the Central Base Station, where the data is processed (Figure 2).

Table 1: Sensors used in the Workstations.

Workstation	Sensors
Leg Press	Load Cell
Jump Platform	Force Platform
Multipower	Load Cell; Displacement sensor

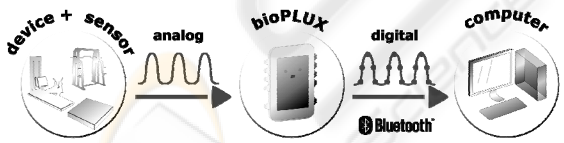

Figure 2: Schematic representation of powerPlux hardware.

4 SOFTWARE

Signals measured by the sensors of each workstations are managed by powerPlux Software Application. It consists of five internal modules: (a) device and sensor configuration; (b) acquisition and display; (c) automatic signal processing; (d) reporting; and (e) database. These modules receive the signals collected at the different workstations in order to determine evaluation parameters, present them in real time and store them in the database.

The architecture of powerPlux software is intentionally simple. A Home Screen allows to choose between the Configuration and the Database sections. The Configuration section is where the coach manages the evaluation devices, protocols, and evaluations. The database section is reserved for accessing athletes' profiles: viewing the historic of evaluations' results and performing new evaluation sessions.

In order to obtain an objective quantification of the athlete's physical condition, reliable and valid data needs to be collected. The design of evaluation protocols may be guided by procedures recommendations published by exercise science experts (Brown et al, 2001). However, the ideal evaluation protocol is not yet defined. Sports scientists and coaches in evaluation laboratories follow distinct recommendations and rules in order to design their own evaluation protocols. Taking this situation into account, we designed a versatile software application that allows the coach to define several parameters for his evaluation protocol and sessions. In this way, a protocol may be costumized according to the athletes' needs and according to the different assessment guidelines. This is done in the Protocol Configuration screen, where the coach may choose the kind and sequence of the evaluations the athlete needs to perform (Reactive Force, Isometric Force or Velocity-Power) as well as a variety of factors that need to be considered when testing: joint angle at which to perform the testing, the rest interval between consecutive repetitions, the number of repetitions to perform (trials and definitives) or the duration of each test. Other evaluation-specific parameters may also be configured for each evaluation protocol.

Once an evaluation protocol is designed and chosen for an athlete, it is saved in the respective page of the athletes' database. The athlete may execute as many evaluation sessions of that protocol as needed.

The evaluation process is guided by visual instructions. A graphic representation of the signal is showed on the screen while the athlete is performing the evaluations, which gives him real time visual feedback of his performance.

In the end of an evaluation session a report os produced with graphic representations of the best execution with companion tables where the results determined automatically by the signal processing algorithms are shown. All the Session Reports are saved to the Database and identified by date and time. For printing purposes, a printable format of the Report may also be generated. In this way, the historic performance progress of the athlete can be easily accessed, allowing follow-up as well as performance gains comparison throughout different evaluation sessions.

4.1 Evaluations

From the analysis of the signals recorded at the different workstations, powerPlux processing algorithms determine standard performance evaluation variables. The fact that the determination of those variables is automated, introduces a new level of objectivity into the evaluation process, allowing a better characterization of the performance of the athlete.

4.1.1 Reactive Force

Jumping is frequently used as a method of evaluation of reactive and explosive force in lower members. The measurement and monitoring of variables such as the jump height, contact time, impulse or vertical velocity are used to study these characteristics.

At the Jumping Workstation, the athlete performs vertical jumps while standing on a force platform that collects the vertical force signal. The processing of this data allows the computation of the standard variables related with the evaluation of lower members reactive force.

Before the evaluation takes place, the coach may configure some specific Evaluation Parameters, namely the kind of jumps the athlete will perform (Squat-jump, Counter-movement Jump or Drop Jump) (Linthorne, 2001), the number of trial and definitive collections and the duration of each collection.

Introduction of algorithm configuration values is also possible. As an example, the force value above which the algorithm will detect the beginning of a jump or the force value for the detection of invalid squat jumps due to the an initial downward movement may be different in distinct evaluation sessions.

powerPlux software automatically processes the force signal measured during the jumps and determinates the performance indicator variables in real time: (a) contact time, (b) gravity center elevation, (c) vertical velocity and (f) impulse achieved in each of the repetitions. These parameters, determined according to standard methods in the literature (Dowling et al, 1993; Linthorne, 2001), are presented while the athlete is jumping (Figure 3) and are stored in the Evaluation Session Report. The squat jump must always be performed in a Reactive Force Evaluation Session in order to assess the relative enhancements in jump performance due to the effect of stretching the muscle/tendon complex prior to contracting. (Linthorne, 2001; Brown et al, 2001). The elevation of the center of gravity achieved in this jump is taken as base value with which the values achieved in counter-movement and drop jump are compared.

Figure 3: Evaluation screen showing the results of a counter movement jump evaluation.

4.1.2 Isometric Force

Isometric assessment of muscular function requires the athlete to push maximally against a resistance, where a measurement sensor is placed, without movement taking place. This test is one of the oldest methods used in sports science.

powerPlux allows the evaluation of isometric force of both superior and inferior members. The test is done at the Multi-Power and Leg-Press workstations, respectively. The devices are instrumented with load cells to measure force data. The algorithms are applied in real time to this data and determine, directly from the force-time curve, the evaluation variables. Figure 4 shows a screen shot of an evaluation of suprior members' isometric force.

Maximum Strength (Maximum Voluntary Contraction) and the speed with which force can be developed (Rate of Force Production) are important variables of the isometric force evaluation (Abernethy et al, 1995; Wilson et al, 1996). These variables are determined by powerPlux software for both superior and inferior members by automatic analysis of the force-time curve and respective derivative. Other important variables are also determined: the percentage of the Maximum Force at the instant when the Maximum Rate of Force

Production is achieved, the Rate of Force Production at 50, 150, 250 and 350ms and the Percentage of Maximum Force at 50, 150, 250 and 350ms.

The evaluation may be unilateral or bilateral, allowing the comparison between both left and right members' performances.

Isometric assessments usually display high test/retest reliabilities (Abernethy et al, 1995). However, reliability varies between the muscle groups, the parameter being assessed (Maximum Force or Rate of Maximum Force Production) and the posture at which the testing is performed (joint angle). In order to facilitate the performance of a comprehensive evaluation and follow-up of the athlete, these parameters are recorded in the report as well as the parameters configured before the evaluation takes place.

Algorithm configuration parameters is also possible for isometric force evaluation Workstations: the Initial Force Value, the range of the derivative and the Acquisition Frequency are configurable parameters which the coach may adapt for different evaluations.

Figure 4: Evaluation screen showing the results of a Isometric Force Evaluation (unilateral).

4.1.3 Velocity-Power

The measurement of power output during exercise gives useful information to evaluate athletes' speed strength (Hori et al, 2006), which can be used as an indicator of performance in most athletic activities. This evaluation can be done with an isotonic test that consists of moving a sub-maximal load against gravity as fast as possible.

Weightlifting exercises are effective training methods to improve speed strength, which makes the measurement of the power output in this kind of exercises a helpful tool for coaches

powerPlux system integrates a Multipower device instrumented with a sensor that measures the time variation of the load displacement when the athlete does the weightlifting. An algorithm determines the velocity and acceleration of the lifting exercise from the displacement data recorded by the sensor mounted on the device (Hori et al, 2006). With this data, Force/Velocity and Force/Power relations can be determined for muscles under the isotonic situation, namely regression equations for force and load as function of velocity.

The maximum amount of weight that can be lifted in one repetition, i.e., the One-Repetition Maximum (1RM) is the most common measure of isotonic strength. 1RM testing involves a trial and error procedure in which progressively heavier weights are lifted until the weight exceeds the subject's ability. The standard procedure involves starting from a percentage of a (estimated) reference 1 RM value and then lifting progressively heavier loads until the heaviest successful lift is reached (Brown, 2001). Before the evaluation takes place, the coach indicates the estimated 1 RM. The lifting evaluation starts with a load of 20% of the reference 1RM and continues with equally spaced increases of loads until the maximum is reached. For each lifted load, the following variables are automatically computed and presented in the report: (a) Mean Power; (b) Mean strength; (c) Mean and Maximum Velocity of the lifted load; (d) Displacement of the load; (f) Time to reach the Maximum Force and (g) Strength Deficit.

Graphical representations of time variation of displacement, force, force/velocity, force/power and force deficit are also presented in real time, giving the athlete feedback of his own work. At the end of each evaluation session Full Power, ratio between 1 RM and Body Weight (1 RM/BW) and ratio between the lifted load and Body Weight (W/BW) are determined and presented in the report which can be used for follow-up purposes.

Some evaluation parameters of the velocity-power workstation may be configured, namely the duration of each test (15s , 30 s, 45 s or 60 s), the time until the start of the test and the type of evaluation (unilateral or bilateral). The Acquisition Frequency is also configurable.

4.2 Reports and Athletes' Database

At the end of the evaluation session, the results and configuration parameters used are stored in the Report. Results are organized in tables and represented graphically for a better understanding and analysis. When several sessions of the same evaluation protocol are performed, additional comparative data, including gain indicators, is generated and added to the summary tables. The several evaluation session's reports are organized by date and time, in order to allow a simple and easy view of the historic evolution of each athlete for follow-up purposes.

The Database is the key point of athletes' management since all the data concerning evaluations and results can be consulted or edited. It includes the athletes' profiles, where personal data as well as reports of previous evaluation sessions are stored.

5 CONCLUSIONS

This paper describes an intergrated, athlete-focused system for automatic athletic performance monitoring and evaluation. Making use of the recent advances in technology, we installed wireless measurement sensors and data acquisition systems in the devices traditionally used for physical condition assessment and designed a specific software that integrates and automatically processes the data recorded by the sensors in real time. The signal processing algorithms are based on standard methods available in the literature and have some configurable parameters that make them adaptable to the specific characteristics of an athlete or group of athletes.

Thanks to the automatic processing of data and generation of reports the amount of time needed for a coach to build and execute an evaluation session is markedly reduced in contrast to the traditional methods.

Each evaluation session is defined by a protocol that is specifically created by the coach for the athlete. In this way, a comprehensive athletic evaluation can be made, showing the weaknesses and strengths of the athelte and helping in the design of a specific and optimized training program.

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