System for Swimming Signals Acquisition and Analysis

Jorge Miguel Silvério do Carmo

Department of Engineering and Management, Instituto superior Técnico

Abstract: Swimming is a sport known for requiring a high level of control of the athlete's physical, technical and mental capabilities. In this context, a swimming coach has a fundamental role in the development of a high competition level athlete. Performance data acquisition helps the improvement of the athlete's performance, by allowing a bigger knowledge of the swimming dynamics. In the last decade, some academic works have tried to improve swimming monitoring and performance data through new technologies. Actually, nowadays there are commercial products with innovative features in the sports monitoring field that are made for swimming. However, none of those products is able to communicate with the coach at real time, leading to the existence of an opportunity to create a new product. Consequently, this master thesis has emerged as an approach for the development of a new solution. In order to overcome that gap, this work begins with the description of the context in which it is included as well as the definition of its main goals. Then, are exposed and analyzed several new product development tools. Thus, according to a product development management perspective, have been studied various performance monitoring systems and techniques. According to this study, it is proposed a new system for the real-time performance monitoring, using BITalino as a tool to support swimming trainers during training sessions.

Keywords: Biosignals, Monitoring, Performance, Swimming.

1. Introduction

In sport, monitoring and performance analysis play a key role in developing athletes since it allows the evaluation of important and necessary information to the athlete's performance optimization and, consequently, prevent possible injuries (Hagem, et al., 2013). In the case of swimming it also enables swimmers compete in the top of physical form (Callaway, et al., 2009).

Swimming, by its nature, is a sport that requires a set of technical skills and specific movements, which define the overall performance of the athlete (Slawson, et al., 2008). The evolution of that performance depends heavily on improving those techniques and movements (Bachlin, et al., 2009; Hagem, et al., 2013), therefore, the coach plays a crucial role in applying training methods to each athlete, so they can improve their technical and personal skills (USA Swimming, 2010).

With the growing competition among athletes, the use of technology as a support tool to improve the monitoring process, through detailed analysis of performance indicators, has gained an important role in training on highly competitive athletes (Slawson, et al., 2008; Pansiot, et al., 2010). In fact, those analysis tools have the potential to provide useful information and additional knowledge and thus increase the feedback in the development of athletes (Slawson, et al., 2008).

Usually, quantitative evaluation of the swimming performance was obtained manually (Davey, et al., 2008) or by video analysis (Slawson, et al., 2008; Callaway, et al., 2009; Sage, et al., 2010). However, with the rapid evolution of technology applied to sports monitoring (Slawson, et al., 2008), in the last few years, small sensors were developed, such as accelerometers and gyroscopes, which are attached to the swimmer in order to collect performance data (Callaway et al., 2009). Indeed, swimmers are becoming more receptive to the use of those sensors in order to improve their performance (Hagem, et al., 2013).

Additionally, the use of those sensors in swimming reduces the need for the coach monitor data manually, thus enabling being concentrated on more technical aspects of the swimmer's performance (Davey, et al, 2008., Bachlin, et al., 2009). However, most analysis systems requires information processing after physical activity (Hagem, et al., 2013), in other words, the information is only analyzed after the training session. For this reason, there is a gap in real-time performance monitoring (Chakravorti, et al., 2013). In fact, the measurement of performance parameters of athletes requires a strong human interaction, sometimes specialized, by using several isolated and independent equipment (Chakravorti, et al., 2013).

In order to overcome this gap this work presents a new approach for acquiring and analyzing signals from swimming activity.

The remaining of this article is structured as follow: in Section 2 are presented several approaches of the Product Development Process. Thereafter, on Section 3 are explained most of current swimming monitoring systems. Then, in Section 4 the new system for acquiring and analyzing signals is introduced and in Section 5 is explained the methodology used on the testing phase. Finally, on Section 6 are summarized the conclusions of this work and proposed some future researches.

2. Product Development Process

In order to better manage the process of innovation, generally, companies use formal procedures like Product Development Process (PDP), which aim to transform small business opportunities into successful products (Cooper, 2008). From all applicable models, the most generic one is the Product Development Funnel that considers an overview of the entire product development process. However, depending on the company or the market, this generic process can be approached by different perspectives, thus leading to the creation of several models (Hauser, et al., 2006).

2.1. Product Development Funnel

The Product Development Funnel is the implementation of three generic phases which describe the evolution of an idea since its creation until it is further developed and transformed into a new product. This model can be compared to a funnel which has as the beginning all the ideas and concepts of the product. Some of those ideas do not pass to the stage of design and development. Thus, the ideas that are sufficiently sustainable for future development and which could become prototypes, are subject to a new filter, where only some of them pass to the testing phase. Finally, there is a launching phase that only is performed for the best ideas, in other words, the most promising ones. This model also considers one feedback version, based on the analysis and review of the ideas in each phase, therefore they must be reconsidered, improved or even recycled (Hauser et al., 2006). The representation of the product development process in this funnel-shaped model takes into account that not all ideas have to reach the design or tests phase and that priority should be given to the most promising ones (Clark & Wheelwright, 1993).

2.2. Stage-Gate Process

In the eighties, a survey on the methods used by companies in the product development process allowed to observe that there was a need for a better model. This new model should provide guidance to project managers by giving specific product information throughout its development and based on market needs. It was also found that a good model should be multidisciplinary and require strong communication between departments. That was the foundation of Stage-Gate Process (Cooper, 1983).

The Stage-Gate Process is defined as a conceptual and operational tool to assist in a new product development project, from idea conception to market integration. The usage of this process aims to improve the efficiency and effectiveness of the product development management. (Cooper, 2008).

3. Swimming Performance Monitoring

The performance of a swimmer is strongly related to his technique; therefore a swimmer who wants to improve his results must devote a substantial part of his workout to improve those kind of skills. However, a swimmer needs to be focused on the correct execution of movements as well as concentrated on coordinate breath with the application of force into the water, which makes it difficult to improve his technique by his own (Bachlin, et al., 2009).

Currently there are several monitoring systems that support the task of observation of the athlete, in the form of prototypes and commercial products. These systems have the capabilities to acquire information and calculate various performance indicators, for instance, the number of strokes or lap times, through various sensors as the accelerometer and the gyroscope. Those small sensors can be placed in the athlete's waist, back, head or wrist, depending on the information to be collected and evaluated.

Currently existing monitoring systems can be used independently or requiring the presence and supervision of specialized technicians, but some of those systems have satisfied a market need and became a product.

However, after analysis some of those products, it was found that none of them has characteristics to inform the trainer about the performance of the swimmer in real time.

The following analysis, showed on the Table 1, it is possible to see that only the work done by Silva, et al., (2012) and Chakravorti, et al., (2013) allows the trainer to access the athlete's performance information in real time.

However, none of these works is currently marketed as a product, so it is possible to identify that there is a lack of systems for monitoring and reporting performance indicators to the coach in real time.

It should also be noticed that all marketed products allow obtaining the athlete's performance of real-time information, but this information is not available to the coach.

Table 1 – Performance Monitoring Systems/Products

References	Product / System	Real-time (Yes/No)	Feedback to the coach (Yes/No)
(Ohgi, 2002)	System	No	Yes
(James, et al., 2004)	System	No	Yes
(Davey, et al., 2008)	System	No	Yes
(Bachlin, et al., 2009)	System	No	Yes
(Khoo, et al., 2009)	System	No	Yes
(Pansiot, et al., 2010)	System	No	Yes
(Silva, et al., 2012)	System	Yes	Yes
(Chakravorti, et al., 2013)	System	Yes	Yes
(Hagem, et al., 2013)	System	Yes	No
(Hobeika, et al., 2013)	Product	Yes	No
(SwimSense, 2013)	Product	Yes	No
(Garmin, 2013)	Product	Yes	No
(Polar, 2013)	Product	Yes	No
(AquaPulse, 2013)	Product	Yes	No

4. The New System

The proposed system has implied that collection of signals is fundamental for the determination of performance indicators, therefore, the development of prototype involves choosing a platform that enables the acquisition of various physiological signals and biosignals. Such platforms require several specific requirements which means higher costs

However, the BITalino is a device that integrates the features needed to acquire signs of this nature, at an affordable cost and with high versatility of hardware components that facilitate their use and boost the development of new projects and applications (Silva, et al., 2014).

4.1. BITalino

The BITalino is a device developed by IT – Instituto de Telecomunicações in collaboration with PLUX - Wireless Biosignals, SA, and consists of several sensors that allow the user to acquire various types of signals. The components essential to the operation of this device, are visible in the central part of Figure 1, those are the microcontroller, the power management module and the communication module. In addition to these, it can be plugged to the base plate several sensors as the Electromyography Sensor, the Electrodermal Activity Sensor, the Light (LUX) sensor, the Electrocariography sensor and the accelerometer. It also gives the possibility to incorporate a Light-Emitting Diode (LED) (Silva, et al., 2014).

4.2. Prototype

The system developed in this project has BITalino as the basis for its prototype. This allows the acquisition of real-time signals using several sensors, getting together the necessary conditions to achieve one of the main objectives of this work, the development of a new system for acquiring and analyzing signals from swimming activity.

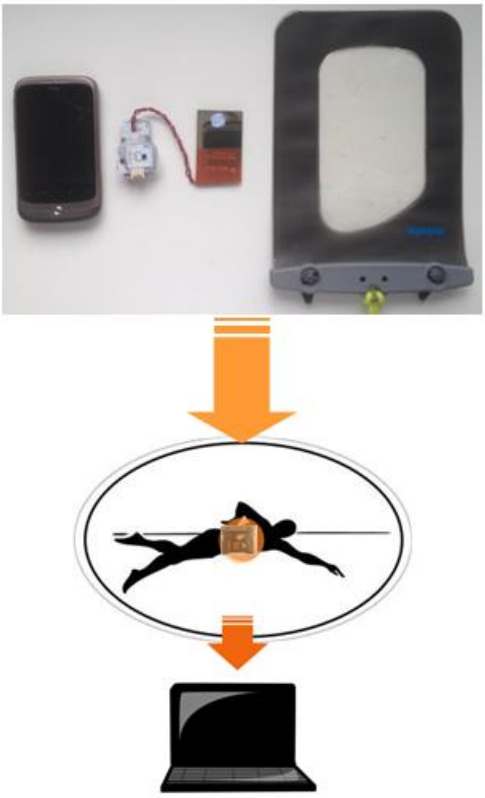

Figure 1 – Proposed System

The BITalino and the base station are part of the proposed system in this section, however, in order to provide useful information to the coach, there is a need for signal processing after receiving it. So, these calculations are ensured by using some of Matlab's features and by two algorithms for analyzing the data acquired by the ECG sensor and accelerometer, respectively.

The algorithms developed specifically for this project consist on three phases: pre-processing; identifying signal characteristics and; indicators calculation. The pre-processing aims to eliminate all the signal noise originally purchased from BITalino, in order to facilitate the task of information analysis. The phase of identification of signal characteristics intends to detect critical points on collected data, in order to subsequently make them usable for the next phase. Finally, the indicators calculation phase is characterized by a specific set of iterations for each case, ECG and accelerometer, which make possible the analysis of the athlete's performance during swimming.

5. Testing Phase and Results

This section presents all procedures performed during the testing phase. The tests are divided into two parts, tests outside the water and tests inside the water. Then, each part is divided into two steps.

5.1. Testing Procedures

The first tests are mainly intended to evaluate the applicability of the prototype to sporting activity and its capacity to acquire signals from both sensors, ECG and Accelerometer, during the workout.

The outside water tests are for evaluation of the device's performance under normal operation condition to ensure that the adaptability to the body is accurate: in this phase it must operate in dry environments and at rest. This will exclude the movements associated with the physical activities of swimming which are included on the second phase of the outside water tests. In this second phase, the objective is to evaluate the capacity of the device to acquire the information from the ECG and the Accelerometer during the exercises done with the machine that simulate the strokes, which are very similar to the movements done under water.

Finally, the underwater tests are divided in two parts. The purpose of the first one is to define the most comfortable and ergonomic localization to place the device. The second phase is intended to understand the capability of the device to acquire the information of the athlete underwater and subjected to all swimming movements.

All the tests were performed on the infrastructures of the swimming team Clube de Natação do Colégio Vasco da Gama (CNCVG). The swimming pool has dimensions of 25x12 meters and have participated ten male high level swimmers with ages between 18 and 26 years old and heights between 1.74 and 1.85 meters.

5.2. Results

In the first phase, the athletes were asked to remain still during a minute. The only sensor working at this sep was the ECG. The results are shown bellow on Figure 2.

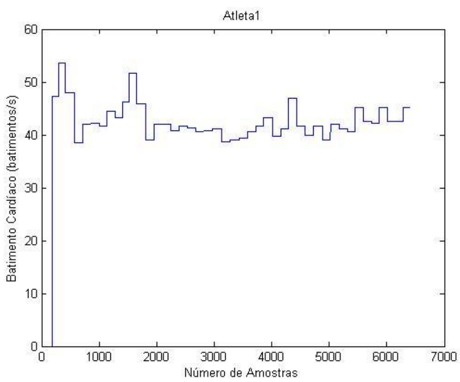

Figure 2 – Heart rate Athlete 1

As can be seen the athlete's heart rate has remained approximately constant, i.e. very close to 40 beats per minute.

Because the athlete stands still, the data originally acquired from the ECG sensor have almost no noise, so that it can be easily processed and analyzed.

However, it is impossible to calculate the same performance indicator during the execution of movements in stroke simulation machine, due to the noise caused by muscle activity of the athlete. On the other hand, the data obtained from the accelerometer in this second stage was clean and let to an easy identification of each stroke done by the athlete in the simulation machine, which demonstrates the ability to apply the BITalino to sports. The results are shown on Figure 3.

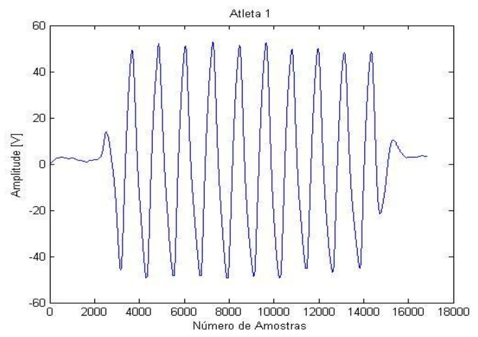

Figure 3 – Strokes on machine Athlete 1

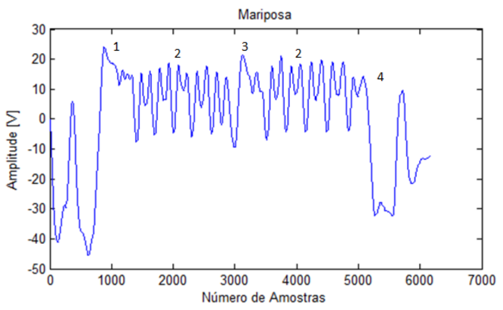

Figure 4 – Butterfly Acceleration Athlete 1

From Figure 4 can be identified four distinct times during the set done by the Athlete 1: the timing of the start, the swimming, the turn and the arrival; identified respectively by the numbers 1, 2, 3 and 4.

Starting with the time of departure, it can be seen that there is a substantial increase in the amount of acceleration module. This increase can be explained mainly by variation of the speed of the athlete at the initial moment of the route, since this pushing wall from a side of the pool.

In turn, this continuous swimming technique is characterized by two distinct moments, the stroke followed by the kick. The graph shows that both moments are repeated on a cyclically basis. In this particular case it can be seen that the athlete performed five cycles in both parts of the set, i.e., before and after the completion of the turn. It is also shown the moment were the athlete performs the turn where exists an increase of the acceleration value. Again, this increased value may be explained by the movement of pushing the wall. Finally, in the final phase of the set can be seen a decrease in the value of acceleration, passing to negative values. These values are explained by the strong impact made by the athlete by reaching the wall.

In an analogous way, there may be seen the same previously identified four moments of the acceleration profile of the breaststroke. This profile is illustrated in Figure 5.

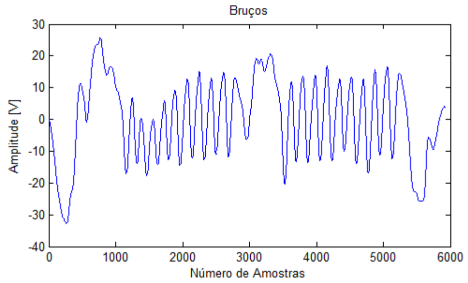

Figure 5 – Breaststroke Acceleration Athlete 1

Both butterfly and breaststroke are simultaneous techniques which have the same basic movement coordination. Thus the moment of touching the wall is carried out with both arms and that's the reason why it can be seen an abrupt decrease of the athlete acceleration value.

Moreover, the backstroke and freestyle techniques share the same basic alternating movements and the moment where the athlete arrives is performed with one of the hands. Thus, as illustrated in Figure 5.6 and Figure 5.7 respectively, there is a considerable decrease in the amount of acceleration module. However, this moment can be identified from the absence of cyclic movements.

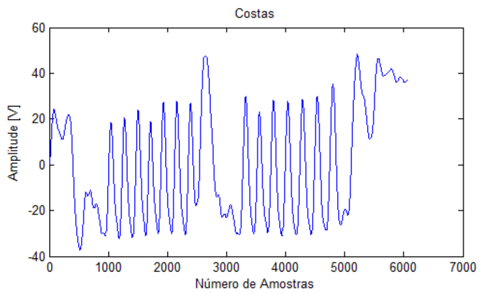

Figure 6 – Backstroke Acceleration Athlete 1

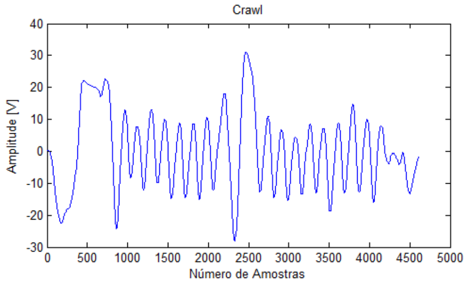

Figure 7 – Freestyle Acceleration Athlete 1

Having analyzed the acceleration profiles of the four swimming techniques related to the athlete 1, it can be concluded that are visually distinguished the four moments previously identified: the swimming, the start, the turn and finishing. Additionally in all four cases the swimming moment is characterized by the repetition of various cyclical movements. Therefore, it is concluded that it is possible to identify and count the number of strokes, starts, turns and finishing moments from the data acquired by the proposed system.

6. Conclusion and Future Work

In short, this project was concluded that the proposed system allows acquiring useful information to evaluate the performance of a swimming athlete. From tests it was concluded that both in dry environment and in water environment information acquired athletes acceleration profile allows to identify key features for calculation of performance indicators.

How prospect of a future work, it is important to mention several issues. Of greater importance, this study lacks a market analysis, phase which includes the last stage of the Generic Product Development Process. After testing the prototype, it must go through an evaluation process of its acceptance in the market. To this should be analyzed some factors such as the size of the target market, the product acceptance level in the market and the same design.

Even as a proposal for future improvement, and in order to overcome some of the limitations observed in this study, a survey of two issues can be realized. First, to analyze the information transmission techniques in existing underwater environment and to evaluate its applicability to the prototype disclosed herein. On the other hand, it is relevant to investigate in ECG sensors enabling the collection of information on the heartbeat of a person in the water.

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