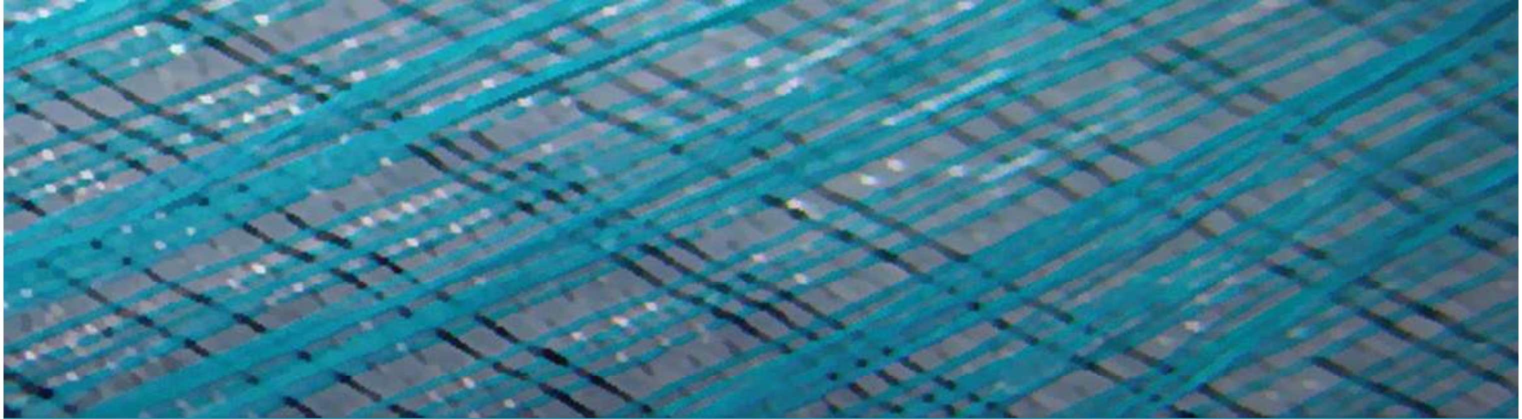

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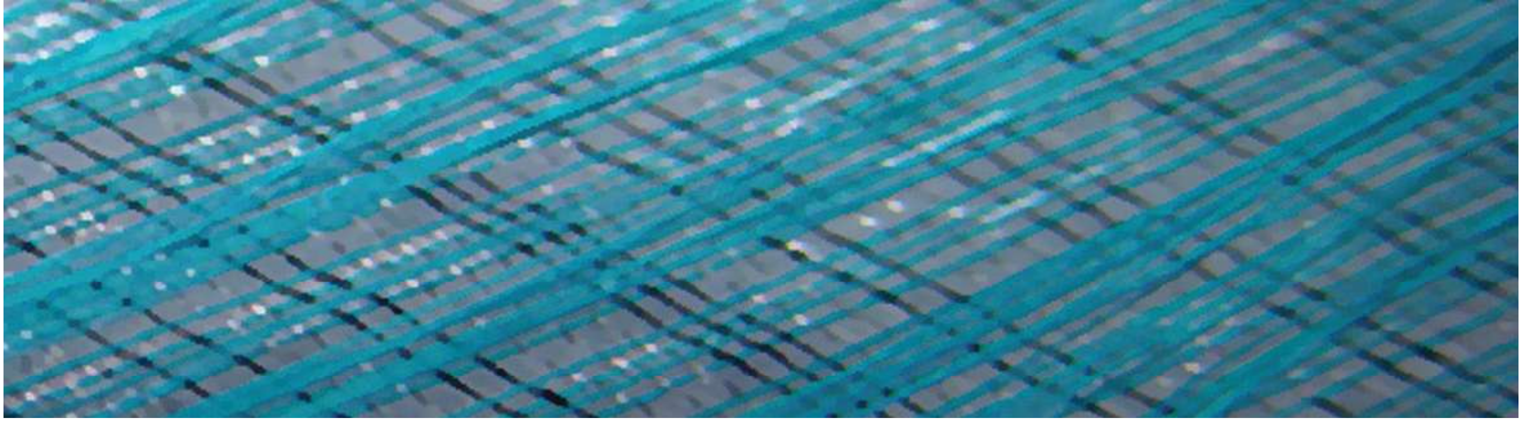

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Foreword

The 41st Textile Research Symposium takes place from Wednesday 12th September to Friday 14th September 2012 at the University of Minho, Guimarães, Portugal. This annual symposium started in 1972 by the initiative of Prof. Sueo Kawabata as a Japanese domestic meeting for the purpose of promoting textile research and communication between scientists and/or technologists. Today it has become an international conference on textile research covering a wide range of fields.

This event takes now place outside Japan in the even years, having already been to China, South Korea and India. This year it is out of Asia for the first time, being jointly organized by the University of Minho of Portugal and The Textile Machinery Society of Japan.

The Symposium will focus on the essential subjects of textile science and engineering covering the most relevant topics and issues relating to textile materials, technologies, fashion, design and marketing. From the 90 received submissions 83 are planned to be presented, 3 as keynote lectures, 62 oral presentations in 2 parallel sessions and 18 poster presentations.

It is a great honour for us to hold this important scientific event. In the name of the organisers we welcome all participants coming from 4 continents and 10 different countries, namely Belgium, Brazil, China (Hong Kong), Czech Republic, France, India, Japan, Mauritius, Portugal and United Kingdom.

Guimarães, 12th September 2012

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Co-chair: Prof. Sachiko Sukigara, Kyoto Institute of Technology, Japan

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Integration of Biosignal Monitoring in Sports Clothing

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Abstract

The present paper gives an overview of the developments achieved in biosignal and sports performance monitoring in the context of the Bioswim project. The Bioswim project aims at developing technologies for integration of conventional as well as embedding novel textile sensors for the measurement, recording and transmission of biometric and performance parameters for athlete monitoring. The study object has been a swimsuit.

Keywords: e-textiles, biosignal monitoring, sports clothing

1. Introduction

The measurement of several parameters that are involved in the performance of an athlete was always of paramount importance for the trainer. Nowadays, small details can determine the difference between success and failure. The better the trainer knows the athlete, the more chances the latter has to achieve maximum performance. This can be done by means of observation, training response, careful season planning, and analysis of parameters that are involved in the exercise that is being performed. In recent years, this specific factor has become of particular importance, since it allows to get the best of the athlete based on his physical capabilities.

On the other hand, the advent of microelectronics is playing an increasing role in the measurement of these parameters. It is now quite straightforward to apply and transport an integrated circuit nearby the athletes without causing significant discomfort. The wire-free communications that is now available, like Bluetooth, Zigbee, Ultra Wide Band, and Wi-Fi can also result in a higher level of freedom for the athlete, by providing the possibility of incorporating monitoring functions in portable devices.

However, there are still some obstacles that need to be overcome in order to achieve measurement of performance and biological parameters with devices that are effectively and unobtrusively attached to the athlete or integrated in into wearable products.

Broadly speaking, one may organize the integration of electronics in three different stages [2]:

- Basic integration, where the electronics is externally attached to the fabrics by means of pockets or special items deliberately developed to accommodate the electronics. This approach is quite popular and simple especially conceived for off-the-shelf solutions, however, it may not be very comfortable for the user;
- Intermediate integration, where the electronics, including sensors, may have some parts incorporated in the fabrics and thus they are not so visible. This approach is well accepted by the user, is more difficult to produce, but still has some problems related with comfort;
- Higher integration, in which the electronics is embedded in the fabrics. This is the most difficult approach to achieve, since it involves having the as an integral part of the fabric without adding any kind of discomfort to the user. It is also the most well accepted approach.

Much work has been presented in the past decade, involving different parameters to be measured and, with different degrees of integration involved. The appearance of conductive yarns able to be integrated into textiles by conventional textile production processes has created possibilities for the increase of integration.

There is much work proposed by numerous researchers in this context. Extension sensors for monitoring breathing rate and movement have been tested with knitted textiles based on conductive yarns, as described in [1-5]. Electrodes for physiological signal sensing, such as ECG, EMG or skin impedance have been investigated and demonstrated in other work [6-12], moisture sensing for monitoring of bed-rest and disabled people has been studied in [13]. In these studies some limitations of textiles as extension or moisture sensors have been observed [2,13] , but generally the performance of the textile electrodes as biosignal interfaces has been found satisfactory [6,8,9].

2. The Bioswim Project

The purpose of this project is the development of an autonomous and real-time monitoring system, able to communicate by wireless transmission and transfer all the recorded information to a laptop computer, where a software application displays the parameters of interest for the trainer.

The parameters of interest are related to:

- Performance parameters;
- Biomechanical parameters;
- Physiological parameters.

These parameters can be further split into the following:

- Physiological: : electrocardiography (ECG); electromyography (EMG) for eight muscles in arm and leg; temperature; respiratory rate;
- Biomechanical: Pressure on hand; goniometry; instantaneous swimming speed; gesture frequency, number of cycles.
- Performance: Swimming time; swimming distance; average speed.

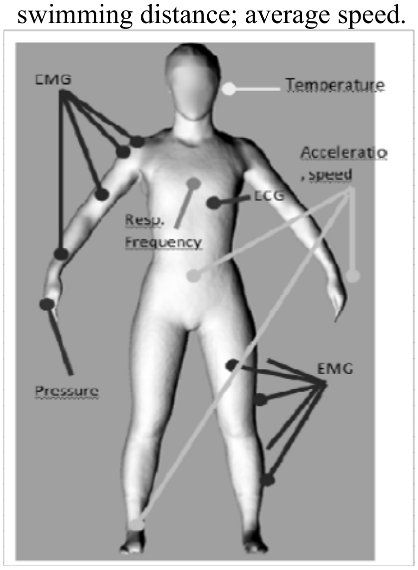

Fig. 1 - Placement of the sensors to be attached in the swimsuit.

It is worth noting that some of these parameters are derived indirectly, from sensors that are present to measure another parameter.

Furthermore, the project is conceived for the development of this system implemented on a swimsuit.

There are several issues that need to be considered:

- The environment is quite uncomfortable for electronics, which means that the swimsuit needs to have an excellent waterproof behaviour.
- Underwater communications are possible, but not using electromagnetic communication. Thus a solution needs to be found to guarantee the communication.
- Not all sensors can be used in the presence of water. For example, the electrodes used for measuring biopotentials usually are made with a pair of electrodes plus reference. If for some reason the amount of humidity present between the electrodes establishes a direct path between them, the bioelectrical signal is lost.
- The number of sensors is quite considerable, which may result in an incapability of sending all the information in real-time. Thus, it is important to carefully consider the amount of information that in fact needs to be sent in real-time and how to send the information after recording a training session.
- The placement of the sensors is quite important, since they should not interfere with the athlete's normal activity, but at the same time it should be integrated exactly where the measurement should be made.

The following sections will give an overview of how the abovementioned issues were tackled. In particular, the embedded sensors used in this project will be presented.

3. Specifications regarding the sensors to be used

Table 1 summarizes the parameters that are intended to be monitored by means of proper sensors, preferably textile based sensors.

Table 1. Main specifications for the parameters under analysis.

Parameter	Required bandwidth (each sensor)
Limb acceleration (3 axes)	200 to 400 Hz
Palm pressure	150 to 300 Hz
Backhand pressure	150 to 300 Hz
ECG	300 to 600 Hz
Respiratory Rate	10 to 40 Hz
Tympanic Temperature	0.1 Hz
Surface Electromiography	500 Hz to 1 kHz

From the kind of parameters one can see that the surface electromyography (EMG), followed by electrocardiography (ECG) are the most demanding, in terms of transmission dataflow. Prior to transmission, the parameters are measured by sensors and the analogue signal is then processed in a first stage that mainly involves amplification and filtering. The analogue signal is transported into the processing stage by means of regular isolated cables, made with copper multifilament and covered by silicone. This assures extra flexibility to these electric cables and reduces the risk of noise. The connections between the cables and the sensors is made using an attachment with a small metal connector and then covered with Teflon. This approach proved to be quite resistant to dress and undress the suit.

Fig. 2- Detail of the electrodes for SEMG and the connections with regular signal wires.

Regarding the most demanding signal, sEMG, the signal is sampled at 1000 samples per second and this signal is transmitted in real time from the wireless node to the coordinator, recorded and simultaneously displayed in the laptop. A overall data rate of about 5000 samples per second has been demonstrated with a data frame loss of less than 2%. The samples acquired have a 12-bit resolution [15].

The wireless modules were developed to accommodate up to four analogue signals that come from different sources, sampled at the adequate rates, organized in a specific format and placed in frames where each signal is well identified, which are then sent to a device called the coordinator, using Zigbee. The coordinator delivers the data to the PC via USB. There is a specific process to determine errors in order to guarantee data integrity [15].

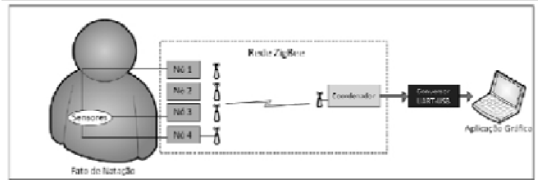

Fig. 3 – Zigbee network.

The developed system is thus able to transmit up to 5000 samples per second with a very small loss of frames, which means that a wireless node can transmit four signals that come directly from EMG of four muscles, besides additional information with less bandwidth requirements. To recover the lost frames, the wireless node is equipped with flash memories, capable of storing a training session of up two hours. This can be accomplished after the training.

4. Construction issues regarding the swimsuit

Due to the specifications it was decided by the research team to split the swimsuit in two layers [14,16], an inner layer carrying part of the sensors embedded in the fabric, or attached, when textile based sensors are not applicable, and an outer layer to maintain the isolation from water and give an extra compression effect. While it is possible to isolate electronics from water by using several methods that basically embed the circuit boards and IC's in an isolated chamber, as well as for several conventional sensors, the same does not apply when one intends to measure biopotentials. This measurement can be based on two electrodes, plus a reference one, and senses the electric potential generated by the chemical reactions in muscles. It is well known that the interface between skin and electrode can be considerable and it can also be reduced by using a specifically designed conductive gel. However, the two electrodes cannot be in direct contact because it would generate a short circuit. So, the presence of water between the electrodes is prohibited. Using an isolating layer may prevent this problem. On the other hand, this isolation may promote an extra perspiration, which on one hand can contribute for reducing the abovementioned impedance, improving the signal quality [9] but on the other hand, increase the possibility of short circuit and thus, no signal may be acquired.

In the present version, only the electrodes for SEMG and ECG are completely embedded in the fabric. The swimsuit was produced using a MERZ model MBS, full jacquard seamless knitting machine, with a 28” gauge. It only presents one needles system, in the cylinder, and transfer jacks in the disk. This machine is equipped with eight systems than combine the cams and a stripper with seven yarn fingers. The yarn is supplied with two different feeding systems, depending on the kind of yarn to be used. If the yarn has does not have elastane, it is used a storage feeder. In case of using bare or covered elastane, one used an electronic feeder (BTSR), which continuously measures the yarn input tension and regulates this fundamental parameter. The team decided to use the plating technique in order to allow the change of yarn from non conductive to conductive yarn, while maintaining a base yarn.

The swimsuit layer that is in direct contact with the swimmer was in its first version made with flat polypropylene and elastane. In specific regions, as can be seen on Figure 4?, this yarn is switched to the conductive yarn and a specific pattern is knitted. Then, the yarn is again switched to the polypropylene yarn.

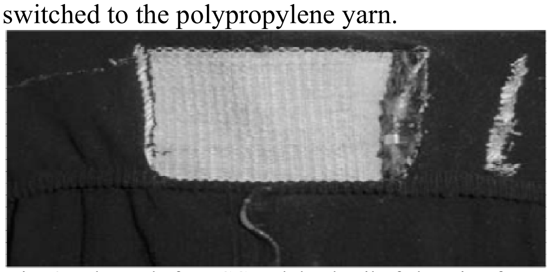

Fig. 4 – electrode for ECG and the detail of changing from polypropylene and the bekitex yarn.

There is always a base yarn made of bare elastane. Previous studies allowed concluding that a 44 dtex bare elastane produced results that may be considered broadly similar in terms of compression as 78 dtex bare elastane [8], which led the team to use the yarn with this linear density. This also allows a reduction in weight and ease of production due to the geometrical dimensions of the needle’s hook.

The structure for textile electrodes for ECG and EMG sensing was produced with a specific pattern, based on experiments made which showed a reduction in the electrode’s impedance. This pattern is drawn in the CAD system, as well as special channels where normal isolated connection wires may be inserted to connect elements throughout the swimsuit. Figure 5 illustrates the swimsuit with the electrodes for ECG.

Fig. 5 – electrodes ECG on the first layer of the swimsuit (left and center image), and SEMG on Rectus Femuris (right image).

The conductive yarns used were a blend of polyester and stainless steel (Bekitex Mn 50/1 from Bekaert) or a yarn made with filaments of polyamide covered with a very thin layer of silver covering a bare elastane core, known as *Elitex*.

It was found that the polypropylene may not be the best solution for the swimsuit. Although presenting an excellent hydrophobic behaviour, this may turn in a disadvantage since after some tests in water it was detected that the electrodes had a tendency to produce short circuits more often, since there was more water surrounding the electrodes than expected. One solution that is presently implemented and under validation involves the application of a very thin layer of silicone surrounding the electrodes. With this approach one can reduce the stretching effect of jersey based fabrics and on the other hand avoid the direct contact of the electrodes with each other.

The second version of the swimsuit was built using polyamide and elastane. This solution presents an interesting advantage in terms of applying the outer isolation layer, finished with silicone (Elastosil).

Fig. 6 – Second layer of the swimsuit, which provides extra compression and waterproof isolation. The arrow pinpoints the glove where the pressure sensors are placed.

5. The effect of Strain in the electrical behaviour

Strain is an important factor, since the swimsuit will stretch while it is being dressed. After stretching,the textile based sensors will present a different shape. Moreover, the movement may change the shape of the sensors, which can result in a differences when compared with conventional electrodes.

The research made so far revealed that depending on the raw material used in the conductive part of the swimsuit, the electrical properties can change with the effect of strain. In fact, Elitex based electrodes showed no change in DC impedance while stretched up to 100%, while the electrodes made with Bekitex show variability, which will depend on the structure adopted and the amount of strain. The same behaviour was observed when analysing the AC impedance, from 15 to 600 Hz. The electrodes based on Elitex were similar to conventional electrodes, even under the effect of strain, while the electrodes made with Bekitex also presented some variability in this electric parameter.

From this research one could conclude that the most adequate raw material for this kind of sensor should be Elitex, since it revealed a high stability in terms of impedance for the different experiments made. This represents an important result, since one can replace conventional electrodes with sensors embedded in the fabric without losing the quality of the signal.

6. The importance of compression for measuring biopotentials

The swimsuits specially designed for competition present a very high compression. The objective of this compression is to reduce the movement of relaxed muscles while their antagonists are contracted [16]. Using this strategy, the swimsuit contributes to a reduction in friction and thus it improves the athlete's marks.

When it is intended to embed sensors in a fabric one should guarantee a permanent contact with skin, not only for the contact itself but also to avoid misplacement during the exercise.
For the case of textile electrodes this is particularly true, since adhesives are not used, only conductive gel. The conventional electrodes use conductive gel together with an adhesive.

The following figures can show how compression may help to stabilize the textile electrode, while the conventional ones produce a signal with more noise. However, the minimum compression necessary to guarantee permanent contact and position stability was not yet determined. This is a work that still is under research. For this particular purpose, the compression is quite significant, in the order or beyond class II medical stockings.

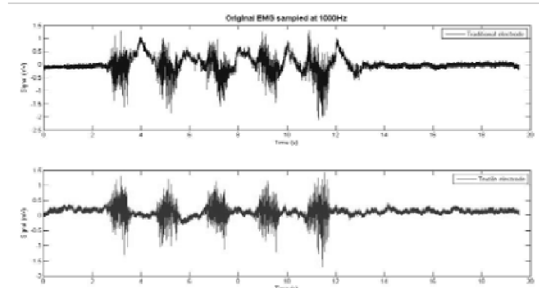

Fig. 6 – Effect of compression on textile electrodes (below) and conventional electrodes (above). The artifacts are more significant in the conventional electrodes than in textile electrodes.

8. Conclusions

The development of textiles with embedded sensors for applications in sports – be it leisure or high-performance sports, is certainly a theme with great market potential in the future. In this project, several issues regarding this application have been tackled in one of the most difficult applications: clothing for swimming. It has been shown that textile-based electrodes for biopotential measurement can be implemented with similar performance as conventional electrodes, with obvious benefits. Electrical connections embedded in the swimsuit have been demonstrated, based on conventional electrical isolated wires routed through textile "channels", as well as knitted into the textile substrate. Electrical insulation using silicone finishing has been used and valid signals have been acquired. Signal conditioning and communication hardware, such as power supply, remain attachments to the clothing. Nevertheless, a higher level of integration has been demonstrated. Future work points in the direction of miniaturization and better integration of the necessary hardware, besides fine-tuning of aspects related to compression, electrical connections and practical aspects such as quick dressing/undressing of the suit and influence of maintenance and care on the performance of the sensors. On the other hand, all the techniques and solutions found will be used in other applications, in less restrictive environments than the aquatic environment for which this project was developed.

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