An initial experience in Wearable Monitoring Sport Systems

A. J. Salazar, A. S. Silva, C. M. Borges, M. V. Correia

Abstract— **Until recent years most research involving the capture and analysis of biometric and/or physiological signals have been limited to a laboratory or otherwise controlled environment. Wearable technologies introduced a refinement to personal signal capturing by permitting a long-term on-person approach. Sensors, integrated circuits, textile integration and other elements are directly responsible for advancements in this area; however, in spite of the present progress there are still a number of obstacles to overcome for truly achieving seamless wearable monitoring technology (WMT). This article presents an overview of a generic monitoring systems architecture based on designs found in recent literature and commercially available solutions. A custom implementation based on commercially available components and evaluation boards is also presented, including some obtained data in varying body locations and/or activities.**

I. INTRODUCTION

MONITORING technology has experienced a boom in the past decade. Not only have sensors, mixed-signal components, transceivers, etc., have become smaller, more powerful and more energy efficient; so have the contributions in communication protocols, textile electronics, and the general interest for body-centric devices for fields such as healthcare, entertainment, personal assistant devices, and sports. Although body sensor networks (BSN) and wearable monitoring systems (WMS), seem to have focused on healthcare related issues, there is a growing trend for electronics development for sports (among other areas). Strategy, performance enhancement and maintenance, training optimization, stress factor estimation, injury prevention, experience level determination, are among some of the objectives of today's sports focused wearable electronic development. This trend is not by any means new, on the contrary it has been observed for decades; technology and sports have gone hand-in-hand for some time. Textile advances, material science, mechanical engineering have affected sport attires, equipments, fields and courts; all which have benefitted from technological advancements (artificial turf instead of grass, sport specific shoes, drag efficient swimsuits, custom competition bicycles, etc.); and for a while now we have observed the use of mathematics and physics for strategy improvement, training optimization, statistical analysis of performance, etc.

Although the overall requirements and sections of monitoring designs can be considered common among most systems, there are intrinsic differences when referring to sports. The need for precise training regiments and physiological and biomechanical parameters monitoring, followed by advances in sports technologies and BSN, has taken the athlete out of the laboratory environment when seeking to improve its performance margin. Within sports performance analysis or an athlete´s signals monitoring, the goal shifts from monitoring the individual to monitoring the response of the individual to its surroundings and the effects that an individual´s condition affects such interaction; while being specific to the sport being studied. For example, if considering a tennis athlete, the focus could be on monitoring the athlete´s grip on the racquet and its reaction to the different plays and serves. On the other hand, if we were to consider climbing, the level of sweat, muscle tone, fatigue and oxygen in blood, among other factors, are key to insure the safety of the climber (well relative safety, the individual is climbing).

II. MONITORING SYSTEMS ARCHITECTURE

Whilst a trend seems to be forming within WMS, for a preferance of commercially available monitoring solutions, referred to as "motes" by some (which tend to be the result of past efforts in wireless sensor networks). There is also a necessity for custom designs which seek to optimize the data collection of the particular project at hand. Their seems to be some concurrence on the general design of a BSN [1]-[3], or in this case WMS (as the particular functional objective). Commercially available "motes" are commonly found as the main elements of BSN and WMS design, some examples are: IRIS, MICAz, TELOSb, SHIMMER and Imote2. These devices are used for capturing and transmitting biomechanical and physiological signals, among other data related to healthcare, sports, motion capturing, etc. These off-the-shelf solutions are a considerable contribution to the field of BSN and WMS, since they permit research groups (specially those that are not electronics inclined) to focus on the captured data and feature extraction algorithms/heuristics, instead of the, sometimes slow process of electronics debugging and troubleshooting.

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Within this article, monitoring systems (MS) will be considered divided in three main sections:

- Sensing section.
- Processing section.
- Transmitting section.

The mentioned sections can be found separate, intermixed or integrated depending on the design, but the objectives of their functions can be readily separated if needs be.

A. Sensing section

Advances in micro-fluidics, material science, nano-structures, micro-electromechanical devices, bioelectrical interfaces, and others; have contributed to a new generation of wearable and implantable sensors and monitoring devices. Healthcare has greatly benefitted from the development of biosensors (also referred to as chemical sensors) [4] and physiological sensors. Such achievements have paved the way for truly pervasive monitoring strategies, which will benefit patients and reduce the load to health-care facilities. From a sport monitoring perspective, non-invasive, minimally intrusive sensors are the preferred choice, and consideration of their positioning, calibration, noise, offset, deviation, etc., are concerns [5]. There exist a wide array of commercially available sensors and even more experimental devices and concepts waiting their turn. Even neuron-electrical devices are being researched which would eventually allow for a direct interface with an individual's nervous system [6]. Due to the number of available sensors, it is important to establish a comparison mechanism for allowing an informed selection process. Key elements to consider when selecting a sensor are [4]:

- Selectivity: capacity to respond to the target signal.
- Sensitivity: change of output per change on signal.
- Range: lowest detectable point and highest detectable point.
- Stability: predictability of sensitivity within range.

Sensors can be classified in a variety of ways including by function or nature (referring to the function the sensors serves, and the nature of the device itself). Regardless of the classification scheme one wants to utilize, the reality is that sensors' complexities have introduced the need for interdisciplinary combination of efforts. A clear example is the efforts seen in the BIOTEX project [7] where a textile based sensor combines electrical, optical, chemical, material science and textile integration, in a non-invasive body fluids analyzer. Due to the complexity of the signals being captured and the analysis that are being attempted, several issues have been raised regarding sensor strategies. Concepts such as awareness, bio-inspired methodologies and multi-perspective source recovery algorithms, have been introduced in order to optimize the quantity and the quality of the data being collected [8], [9].

B. Processing section

In today's market, the competition to claim to be the lowest powered microcontroller is fierce. Depending of the complexity required by the application and the feature extraction methods to be applied, an array of Reduced Instruction Set Computer (RISC) or Advanced RISC Machine (ARM) architecture based microcontrollers offer different features which accommodate varying solutions. Based on the popular "motes" designs and further research in the area, there seems to be a preference for Texas Instrument MSP430 ultra-low power, Atmel's ATMEGA ultra-low power, and the Microchip's extreme-low-power (XLP) PIC microcontrollers. Using the power specifications, indicated on the datasheet of each microcontroller, as a base for comparison, can sometimes lead to problems and confusion; careful attention must be paid to the conditions in which each manufacturer measures their devices power consumption.

Field Programmable Gate Arrays (FPGA) and other alternatives to low-power microcontroller, offer a flexibility and updatability which can not be match by the later. It is true that the power consumption characteristics and non-recurring engineering cost of FPGAs are not at the same efficiency level of their microcontroller counterpart; but for prototyping custom IC solutions, or testing hardware based feature extraction methods, they offer unrival benefits. Microcontrollers are limited to their instruction set and architecture as opposed to FPGAs that can be program to physically represent a wide variety of electronic devices, including microcontrollers. Today's FPGAs offer a wide variety of features including Power PC modules, digital signal processor (DSP) modules, computer arithmetic efficient modules, among other things. While it might be considered excessive to include an FPGA in most WMS designs, they can prove useful for applications that seek on-body complex processing. A number of techniques are being applied for reducing the power consumption of FPGA including: cell specific power management, DDR3 and dynamic on-chip termination (OCT), among other strategies.

C. Transmitting Section

When referring to WMS, it is unavoidable to consider a wireless component for interfacing with the system; either be it for real-time (or continuous) or sporadic updating to a remote processing node, or for downloading the collected stored data, or even for transmitting the data from a sensor node to the on-body or remote processing unit. The presence of cables or the need for physical removal of the device for data download represents an alternative that while permissible at prototyping and troubleshooting stages, is impractical at more advance stages of design and implementation.

A number of alternative exist for mid-range wireless communication including common protocols (GSM, WiMAX, UMTS, WLAN, etc.) and upcoming 4G mobile communication solutions. From a more local point of view the IEEE 802.15 Workgroup has introduced an array of solutions. Among the favorite standards one counts with the IEEE 802.15.1, known as Bluetooth, and the IEEE 802.15.4, also referred to as Zigbee. Table I compares the most common wireless communication standards, including the medical implant communication service (MICS), thought for the new generation of implantable medical devices. The number of low-power short-range transceivers in the market today is enough to overwhelm even experienced researchers. It seems every brand offers their particular RF solution, claiming low-power transmission; companies such as Texas Instrument, Atmel, Semtech, Maxim and Microchip (to mention a few), offer interesting and varying solutions. Texas Instrument's CC2420 (or its second generation version CC2520) is constantly used within commercially available "motes", MCU-transceiver integrated solutions, and custom WMS designs in literature at the present time.

TABLE I
WIRELESS COMMUNICATION STANDARDS COMPARISON

	Range	Data Rate	Frequencies
IrDA	1m	16 Mbit/s	Infrared
MICS	2m	500 Kbit/s	402-405 MHz
		20 Kbit/s	868 MHz, 1 Channel
Zigbee	10-75m	40 Kbit/s	915 MHz, 10 Channels
		250 Kbit/s	2.4 GHz, 16 Channels
Bluetooth	10-100m	1-3 Mbit/s	2.4 GHz, 79 Channels
802.11g	150-200m	54 Mbit/s	2.4 GHz, 13 Channels

Extracted from standards websites and [3]

III. RESULTS

A first prototype was designed and implemented with commercially available components and evaluation boards. This inertial measurement unit (IMU) was developed using a Freescale MMA7260QT accelerometer and an Invensense IDG-300 gyroscope evaluation board, a Texas Instrument eZ430-RF2500 target board and battery pack. The system has a total cost under one hundred Euros, with an implementation time of a couple of weeks (mostly dependant on components arrival, the PCB design and fabrication time) and weights less than 50 grams (without batteries), while measuring 57x90.5x24 mm, as seen in Fig.1.

a)

b)

Fig. 1. Inertial measurement unit. a) Top view; b) Bottom view.

A computer interface was implemented for data processing and visualization on National Instrument's LabVIEW platform (a screen of the interface can be observed on Fig.2). The interface allows for COM port parameters configuration and visualizing of wireless signal strength and data from the accelerometer, the gyroscope and the temperature sensor (which is part of the eZ430-RF2500 End Device board). The eZ430-RF2500 comes in two parts: an Access Point (AP) board and an End Device (ED) board. The ED board (can be observed as the red board on the left side of Fig. 1a.) was incorporated in the IMU, while the AP board served for linking the IMU to the before mentioned interface (the AP section can connect to the computer through USB). Because of the eZ420-RF2500 inclusion, the IMU system is ready for additional sensor nodes and can form a BSN for evaluating biomechanical parameters at different points of the body.

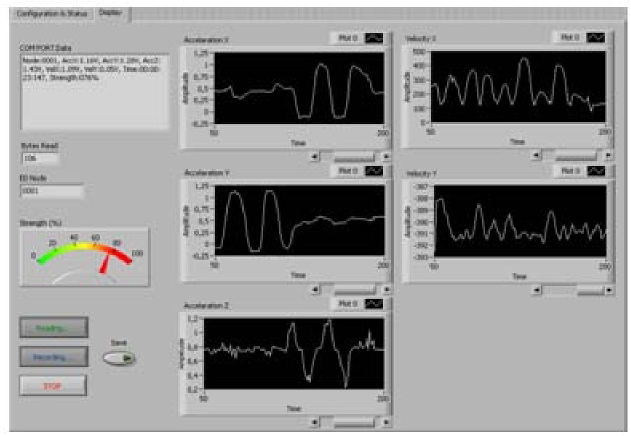


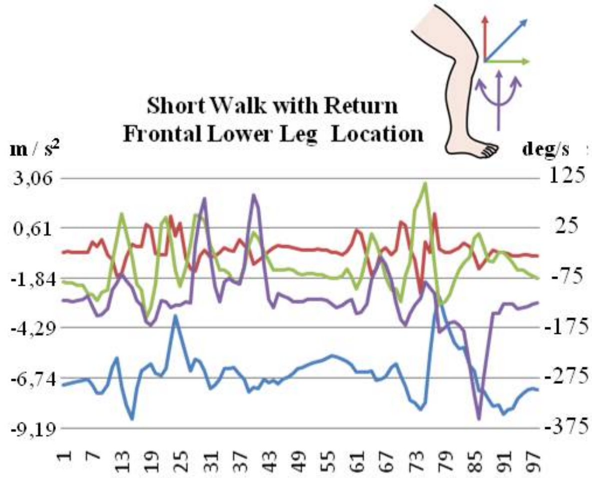
Fig. 2. Data visualization section of the computer interface application.

Preliminary testing revealed that the battery pack allowed the IMU to record and transmit continuously, without any noticeable performance reduction, for periods of 30 minutes under normal conditions (direct line of sight with AP board and a relatively close distance). Modifications are underway to adapt an SD card port to the IMU in order to provide local long term data recording.

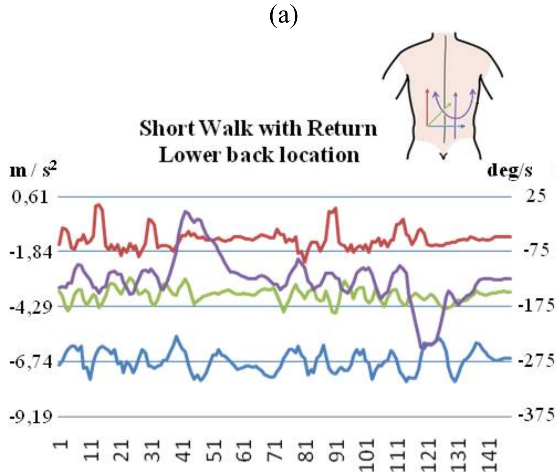
A. Preliminary Data

Due to the IMU's size and low weight it can be situated on several places over the body, for analysis. Some data collection was performed on a number of activities, demonstrating the IMU's flexibility. Examples of such activities are: walking, running, tennis swing, swimming, etc. Although the data does not produce the traditional analysis graphs, such as for gait analysis, they do provide insight in the local and global actions and reactions of the site were the IMU was located.

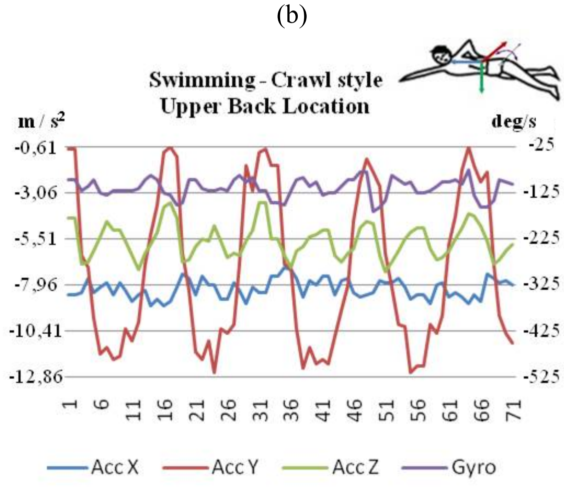
Fig. 3 shows graphs of smoothed un-calibrated accelerations and angular rate for a), b) walking and c) swimming. The X axis can be considered vertical and together with the Y axis forms the frontal plane of the subject; while the Z axis points forward, for the lower back location (same as for the lower leg case), with respect to the direction of movement. For the graphs in Fig. 3a, and 3b the subject performed six steps, turned back and returned with another six steps. The graph of Fig. 3c shows four cycles of a crawl swimming trial. In this last case, the X axis points in the direction of displacement and together with the Y axis forms the frontal plane of the subject, while the Z axis is pointing inwards at the upper back location.



(a)



(b)



(c)

Fig. 3. a) Walking and return with IMU located at right front lower leg; b) Walking and return with IMU located at lower back; c) Swimming Crawl style with IMU located at upper back

IV. Conclusion

There is a clear paradigm shift in the approach to signal monitoring which seems to benefit healthcare, assistive technology, entertainment, and sports among other areas of research and industry. Not only has sports performance analysis gained a new foothold on uncovering factors behind an athlete execution; it is also providing mechanisms for insuring their safety from injury and long term ailments. WMS and BSN are the result of numerous advances and miniaturization in IC, MSC, wireless communication, textile technology, SoC, sensors; and signal processing integration within the mentioned technological areas. It is clear that efforts are being made throughout the academic and research community for developing wearable technology and although the focus of the projects vary from sports, healthcare, economics, entertainment, etc., all the solutions offer insights into each other's target problems. The proposed design seeks to present an adaptable, mixed signal module which can be used for monitoring (or even control applications with modifications); such solution is a first attempt and will undoubtedly change with the continuous new offers in the commercial component market.

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