Wearable Monitoring Sports Systems

A.J. Salazar Escobar, *Member, ACM, SOVEB, CETA*

***Abstract*—Until recent years most research involving the capture and analysis of biometric and/or physiological signals had been limited to a laboratory or otherwise controlled environment. Such research, although useful in its own right, failed to consider real life scenarios and their impact on the subject. Wearable technologies introduced a refinement to personal signal capturing by permitting a long-term on-person direct-contact approach. One can equiparate such advance to biologist's "in vivo" experiments, where although some variable remain under control, there is a number of elements that remain statistically unpredictable. The fast paced developments of Body sensor networks (BSN) allowed the next stage in human behavior analysis tools, permitting a new level of understanding on the interaction of individuals with their surrounding environment. Sensors, integrated circuits (IC), textile technology 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). Among the limiting factors for extending such technology, energy availability is the number one concern. Other factors of interest are textile integration, wireless communication, mathematical extrapolation, biomechanical models, among many more. One such obstacle that remains unmentioned in most arenas is the capacity for system testing and self-correction, which has become IC technologies bottleneck and a significant factor in cost. Although testing mechanisms are necessities for any system that attempts long term monitoring, little has been done in this area for WMT. Today's more known wearable strategies are described; including: sensors, processing and data transmission. Finally a proposal for a solution which considers all mentioned factors is presented.**

***Index Terms*— BAN, BSN, wearable sensor, biosignals monitoring, sports performance.**

I. INTRODUCTION

WORDS such as ubiquitous, pervasive, ambient, and seamless are common among most technological research areas of our day. The search for integrating the individual within areas of technological development never has been more sought after, and among so many and varied fields. Commercial products are, with each passing day, smaller, more energy efficient, and more importantly: designed to be portable. The need for an individual to remain "free" seems to dominate most electronic consumer markets.

This trend of centering on the individual has affected the way we perceive signal monitoring as well. It must be said that this ego-centric approach is not by all means a new concept, especially when referring to biosignals capturing. Since the days of the space race in the Mercury project, and subsequently the Apollo project, the need for closely monitoring the astronauts' biosignals was of great importance; which led to their suits to consider the presence of biomedical connections. It has been with advances in integrated circuits (IC), wireless sensor network (WSN), signal processing, etc., in a truly multidisciplinary effort (electrical, biomedical, medicine, textile, among others), that never before has the world seen so many systems designed for monitoring an individual's performance and reactions, as in the last decade.

There are multiple paradigms shifts taking place, were the single moment is being replace by continuous long-term data gathering (instead of a doctor's consult, a patient's data can be gathered for days or weeks); the laboratory or controlled environments is being replaced by real-life scenarios (individuals can interact with their natural surroundings, such as "in vitro" experiments lack the depth of "in vivo" experiments); and database analysis is being replaced (although more complete and complex databases are also emerging) by real-time analysis (where data gathering can change an athlete's strategy mid-event). These conceptual changes are accompanied by a new group of concepts, methodologies and technologies.

Concepts such as Body Sensor Networks (BSN) and Wearable Technology (WT) have become well established in the scientific community and industry as well, giving way to an unprecedented number of designs with a wide variety of objectives. Likewise, sensors have advanced not only in complexity and accuracy, but maybe more importantly, in size and flexibility. Implantable devices, textile integrated circuitry and other achievements have allowed for designs that require less energy and remain on site for longer periods of time; and although medical research and healthcare seem to guide the crest of this technological movement, entertainment and sports have a say as well.

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 his/hers performance margin. Within sports performance analysis or an

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Professor A. J. Salazar Escobar, is an Associate Professor at the University Simon Bolivar where he is the founder and coordinator of the Center for Assistive Technology (non-profit organization that designs and implements low cost solutions for children and elderly in need of assistive technology). Currently Prof. Salazar is at the University of Porto pursuing a doctoral degree in Electrical and Computer Engineering focused in biosignals monitoring through wearable technology under the supervision of Prof. Miguel Velhote Correia.

athlete´s biosignals monitoring, the goal shifts from monitoring the individual to monitoring the response of the individual with 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 for insuring the safety of the climber (well relative safety, the individual is climbing).

II. Monitoring systems

Body Sensor Networks (BSN) generally refers to wireless networked wearable electronic devices which seek to measure an array of chemical, physiological, movement or position changes (among other types of measurable features) of an individual. In 2002 the term BSN was introduced by Prof. Guang-Zhong Yang of the Imperial College (London, UK) who has spearheaded efforts in this field, initially for medical applications and more recently in sports (Yang, 2008) and other area. Prof Yang is also responsible for more than 200 original articles and is the editor of one of the field’s most relevant books (Yang, 2006); which contains a very complete recompilation of WSN and BSN early history (Aziz, et al., 2006), design considerations, applications, and more. In 2004, the Engineering in Medicine and Biology Society (EMBS) established a technical committee on wearable biomedical sensors and systems (WBSS) (EMBS, 2008), thus recognizing this field’s importance and the need for its further development. It was such committee which established that a typical architecture of a WBSS should seek (Bonato, et al., 2006):

1. To sense biomedical signals/parameters on user and/or environmental conditions.
2. To route signals/data to a processor (worn by the user).
3. To process signals/data to compute medical and/or environmental parameters (e.g., heart rate, CO level).
4. To interpret parameters.
5. To diagnose conditions and determine the necessary response.
6. To transmit signals, parameters, diagnosis and response to remote monitoring site.
7. To provide a user interface that enables interaction.
8. To execute responses on/by the user.
9. To learn from experience.

By the year 2005, there already existed a significant number of BSN solutions, including the MITes, CIT sensor node, BSN node, iMote 2, XYZ sensor node, Telos, M1010, Mica-Z, Tmote sky, Pluto EmberNet, etc. (Lo, et al., 2005). All these system attended particular scenarios and while possesing commonalities among their designs and componentes, they were not by all means mirror copies of one another. Prior to these body-centric focused designs, WSN paved the way (Akyildiz, et al., 2002), some examples which challenged the creativity and vision of many researchers were: SensoNet and Aware home (GeorgiaTech), WINS (UCLA), PicoRadio (U.C. Berkley), PACMAN (USC), COUGAR (Cornell), among others. The Smart Dust project of the University of California Berkley, although initially a DARPA funded project, seems to have sparked a number of advances in design, protocols, integration, etc. (Warneke, et al., 2001) (Warneke, et al., 2001); setting the tone for smaller, more efficient and less power consuming sensor systems. The fast pace development of BSN moves hand in hand with advances in what could be considered the most challenging obstacles (Lo, et al., 2005) (Lo, et al., 2007) (Tufail, et al., 2009): Biosensor design and packaging, power sources and energy harvesting, low power wireless communication, intelligent sensing and data fusion, standards and integration. The topics of sensors and wireless communication will be covered more in depth later in this article, so we take the opportunity of focusing on the remaining elements at this point.

A. Energy Considerations

Although energy harvesting and portable energy sources are not a subject intended to be covered in this article, it must be said that worldwide efforts are being focused in this area. There is a clear and present need for body portable long lasting power sources for all kind of electronic devices. Due to the increase in computational power, portable electronic devices energy demands are restricting further advancements. BSN and wearable monitoring systems (WMS) are no exception to this energy shortage, and have benefited greatly of the need of consumer electronics to have more efficient, smaller and longer lasting power sources. Micro-fuel cells and biocatalytic fuel cells are just the tip of the iceberg regarding strategies for more efficient energy supplies, and although strives in this field are being accomplished, yet another approach seems to be gaining momentum: energy harvesting. Energy harvesting can be accomplished through passive or active approaches (referring to the action of the individual to generate the energy), so be it by thermo-electric, electromagnetic, kinetic, piezoelectric, electrostatic, magnetostrictive, among others mechanisms. Some successful implementations have improved the duration of regular power sources; although they are not quite able to supply all the required energy (Khan, et al., 2009). Another approach that shows promise is the use of supercapacitors as energy buffer, for achieving high-power output levels from low-power supplies (such as in energy harvesting strategies) (Mars, 2010). Dr. Dewei successfully summarizes the current state of affairs of energy harvesting strategies, and their fundamentals in his 2009 article (Dewei, et al., 2009). For a comprehensive immersion on portable energy sources (or batteries as some prefere to refer to them) and their devices and systems, Dr. Gianfranco Pistoia’s 2009 book “Battery operated Devices and Systems” proves to be a necessary consultation venue (Pistoia, 2009).

B. Standards and Integration

Although a number of standards, conventions and international agreements have been made with regards to wireless communication, including considering BSN in particular, it seems modest attention (in comparison) has been paid to other aspects of BSN design. Regarding communication protocols one can mention: ANT, 6LoWPAN, DASH7, ONE-NET, ZigBee, Z-Wave, Wibree,

WirelessHART, among many others; including the IEEE 802.15 for Wireless Personal Area Networks (WPAN) and its Body Area Networks (BAN) task group 6 (Heile, 2010). There is a clear need for such a fast pace developing field to organize and establish standards which permit elements reusability. Through the examination of articles published in this area, it is clear that repetition of efforts occurs; and although some publications and organizations have set the tone (the "Body Sensor Network" book and the Body Sensor Network annual conference are to be noted), no clear set of standards has been set. Standards seek not to compartmentalize the designer, but to insure the compatibility of his/her design. Considering the increasing number of sensors, microprocessor, field programmable gate arrays (FPGA), digital signal processors (DSP), wireless communication modules; there exists a disarray of power, interface and protocol requirements that generally work as obstacles in the detriment of the project.
Standards also contribute to module integration within the same package. Systems on Chip (SoC), and other intellectual property (IP) core sharing methods, are becoming more common place with each passing day; allowing for process to occur within an IC, avoiding parasitic elements and other factors that affect signal integrity when signals must navigate from one package to another. In order to achieve seamless integration among the different designs, modules, cores and technologies, while at the same time protecting IP, and understanding between industry, designers and other IP core providers must be reached regarding communication protocols (at all levels, especially within packages), power requirements, testing protocols, and many more issues.

III. Monitoring System Architecture

Whilst a trend seems to be forming within WMSs, for preferance of commercially available monitoring solutions; referred to as "motes" by some (which tend to be the result of past efforts in WSN). There is also a necessity for custom designs which seek to optimize the data collection of the particular project at hand. These two tendencies coexist harmonously, lenning on one another when necessary. Their seems to be some concurrence on the general design of a BSN (Van Laerhoven, et al., 2004) (Tufail, et al., 2009), or in this case WMS (as the particular functional objective). Such concurrence seems to follow the BSN node project (Lo, et al., 2005) (we say seems, because of the academic literature dominance of such design, but a number of designs such as Imote2, MICAz, TELOSb, etc., have commercially available models which are dominating the WSN research) and other similar approaches.
Annex I contains a features comparison of the most popular, commercially available, sensor network "motes" (only designs with wireless capabilities were included due to the nature of this research although other designs such as the Arudino based Lilypad are freely available). The IRIS, MICAz, TELOSb, SHIMMER and Imote2, are commonly found as main elements on BSN and WMS designs, used for capturing and transmitting biosignals and other data related to healthcare, sports, motion capturing and other research areas. These off-the-shelf solutions are a considerable contribution to the field of BSN and WMS, since they permit research groups (particularly those that are not electronic proficient) to focus on the captured data and feature extraction algorithms/heuristics, instead of the sometimes slow process of electronics debugging and troubleshooting process.
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 (allegoring to Von Neumann's, and his colleagues', computer architecture).

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) (Patel, et al., 2006) and physiological sensors, which can be implanted and allow for ECG recording (Medtronics, Reveal), glucose monitoring (Brown, et al., 2005), blood pressure (CardioMEMS) and pH (Metronics, Bravo) measuring. Such achievements have paved the way for a truly pervasive monitoring strategy, which will benefit patients and reduce the load to health-care facilities. From a sports monitoring perspective, implantable sensors are not the device of choice (at least for now). Non-invasive, minimally intrusive sensors are the preferred choice, and consideration of their positioning, calibration, noise, offset, deviation, etc., are concerns (Yang, et al., 2006). There exist a wide array of commercially available sensors and an army of experimental devices and concepts waiting their turn. Figure 1 illustrates the versatility in technology implementation of common sensors such as accelerometers, gyroscopes and magnetometers. Even neuron-electrical devices are being develop which would eventually (we are still decades away by conservative estimates) allow for a direct interface with an individual's nervous system (Maher, et al., 1999).

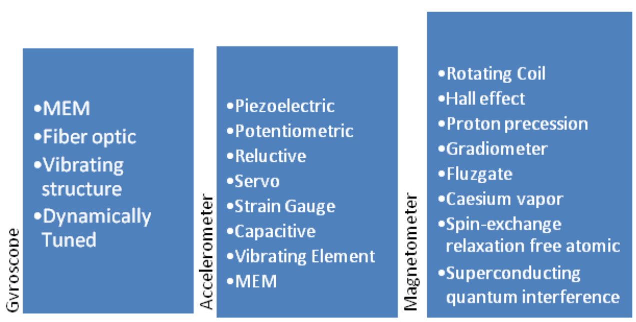

Figure 1. Common sensors types listing

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 (Patel, et al., 2006):

- 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.

Table 1. Sensor classification

Nature	Function
• Biological • Chemical • Electrical • Mechanical • Textile • Optical	• Kinematics (accel., velocity, etc.) • Kinetics (force, press., etc.) • Acoustic (sound, etc.) • Positional (angles, inclination, etc.) • Electric (EMG, ECG, EEG, etc.) • Chemical (PH, ammonia, S20, etc.) • Biomedical (temp., heart rate, etc.) • Ambient (humidity, temp., etc) • Visual (img. capt., color sensing)

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) as seen on Table 1. 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 (Coyle, et al., 2010) where a textile based sensor combines electrical, optical, chemical, and material science in a non-invasive body fluids analyzer.

Due to the complexity of the signals being captured and the analysis 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.

1) Context Awareness

In the search of pervasive monitoring strategies, it is inherit that the concept of context awareness be included within data collection and analysis methodologies. Particularly in sports performance, one seeks to extrapolate physiological data over the actions of an athlete, in order of gaining insight on how to improve or maintain their performance. Under such consideration, it is clear that one must relate the data gathered in context to the actions performed. Since it is natural that the behavior of an individual has direct effects over the physiological data collected, one can adapt the monitoring devices to optimize the data based on the contextual scenario taking place; in this way saving resources and improving the value of the data being transmitted or stored (Surapa, et al., 2005).

2) Multi-sensor fusion

It is common to have multiple sensors monitoring signals that interfere with one another. For example, when capturing ECG additional information in captured as well, such as breath rate, noise, etc. (Lo, et al., 2006). Such interference or superposition complicates efforts of pattern recognition, machine learning and feature extraction. Concepts such as source recovery have been introduced in order to solve these scenario (Lo, et al., 2006); and to gain improved insight into multi-source signal variation.

3) Autonomic Sensing

Bio-inspired methodologies have been commonly seen within fields such as operational research, mathematics, engineering, physics, etc. Sensors are no different, especially considering the complexity of a long-term, low-power, "on-body" monitoring system. Following IBM's "Autonomic Computing" concept (Kephart, et al., 2003), autonomic systems aspire to:

- Self-management
- Self-configuration
- Self-optimization
- Self-healing
- Self-protection
- Self-adaptation
- Self-integration
- Self-scaling

Although some of these properties are not readily applicable to the monitoring devices, conceptually they offer a basis for a more robust and reliable design. Professor Guang—Zhong Yang, and his colleagues, greatly contributes to the understanding of these concepts with his work found on chapter 10 of the book Body Sensor Networks (Yang, et al., 2006).

In order to facilitate the search for sensors, Annex II contains a compilation of companies that offer an array of sensors and accessories. The list presented is limited in nature and does not intend to represent a complete compilation of all the companies that offer monitoring solutions or sensors. Due to the fast paced development observed in the field it is likely that new companies will continuously become available in the market. Due to the international location of these companies, they might not be able to send their devices to all locations, so a direct inquiry regarding international shipping is recommend prior to consideration.

B. Processing section

In today's market, the competition to claim to be the lowest powered microcontroller is fierce. In Annex III, we observe a side-by-side power requirements comparison, of some popular commercially available microcontrollers, often used in BSN and WMS. 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. From the popular "motes" designs (seen on Annex I, and further research in the area) there seems to be a preference for the Texas Instrument MSP430 ultra-low power, Atmel's AVMEGA ultra-low power, and the Microchip's extreme-low-power (XLP) PIC microcontrollers (phrases such as ultra-low, extreme-low, etc., are common place in current component energy characteristic description). Marvell Technology Group's 2006 purchase of Intel application processor division shifted operations to more commercial venues, such as smart phones, set-top boxes, routers, etc. Its PXA320 series (which replaced the PXA270 more known series) now focuses on multimedia demanding applications (based on Windows CE or Linux OS). Other processors worth mentioning are the low-power S08GW series devices from Freescale Semiconductor, used for remote metering (water, gas, electric) applications. Utilizing the power requirements 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 company measures their devices power consumption. Misleading comparisons are a part of the continuous race to claim the position of lowest power consuming device (Albus, et al., 2009) (Mitchell, 2004).

Field Programmable Gate Arrays (FPGA) and other on-site programmable 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 (NRE) cost of FPGA 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 (when compared to microcontrollers and even digital signal processors, DSP, depending of the application, refer to Dillard's 2008 article for a concise and useful comparison of DSP and FPGA). While microcontrollers are limited to the instruction set and architecture, FPGAs 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 processing (DSP) modules, computer arithmetic efficient modules, among other things. While it might be overkill to include an FPGA in most WMS designs, they can prove useful for applications that seek on-body complex processing. Two companies seem to dominate the FPGA market: Xilinx with their Spartan and Virtex series and Altera with their Stratix series. 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 (Altera Corporation, 2010) (Xilinx Inc., 2010).

C. *Transmitting Section*

When referring to wearable monitoring technology, it is unavoidable to consider a wireless component for interfacing to the system; either be it for real-time 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 (or memory storage) for data download represents an alternative that while permissible at prototyping and troubleshooting stages, is impractical at more advance stages of design and implementation. When referring to BSN an alternative to traditional radio frequency (RF) transmission is inductive coupling and other in-body alternatives (Higgins, 2006). For the purpose of this article it will be assume that the transmission device remains outside of the body (no implantable solutions will be considered). An abundance of literature can be found in this issue due to its popular nature. For the purposes of this article the content will be limited to aspects of interest from a WMS point of view.

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 and arrays of solutions. Among the favorite standards one counts with IEEE 802.15.1, known as Bluetooth, and the IEEE 802.15.4, also referred to as Zigbee (in spite of being an incorrect reference since ZigBee entails a much wider group of specifications). Table 2 compares the most common wireless communication standards, including the medical implant communication service (MICS), thought for the new generation of implantable medical devices.

Table 2. Wireless Communication Standards Comparison

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

Extracted from standards websites and (Pantelopoulos, et al., 2010)

The number of low-power short-range transceivers in the market today is enough to confused even well versed researchers. It seems every brand offers their particular RF solution, claiming low-power transmission; Annex IV shows a compilation of commercially available transceivers and some of their features. In spite of the variety of transceiver (and the claims they might present), one module seems to be the standard: TI CC2420 (also referred to as the Chipcon CC2420, prior to the companies purchase by Texas Instrument). This Texas Instrument transceiver is widely utilized, in pair with the MSP430 microcontrollers and in any design seeking low-power IEEE 802.15.1 compliant RF solution. The CC2420 consumes 19.7 mA RX and 17.4 mA TX (Texas Instrument, 2007) and has originated a new series of second generation SoC and transceiver solutions. It should be noted, that companies such as Atmel, Semtech, Maxim and Microchip (to mention a few), also offer interesting solutions that can outperform the CC2420 (under specific circumstances), the reason it is referred in this article as the standard on RF transceiver is due to its constant use within commercially available "motes", MCU-transceiver integrated solutions, and custom WMS designs in the researched literature at the present time. Factors such as cost and availability could also affect a designer's decision, since some models can only be purchased in bulk or not offered to non-industry customers.

IV. Testing Considerations

Although much can be said of the importance of testing and design for testing in this age of Systems on Chip (SoC), mixed signal ICs, and hybrid technologies IP modules sharing common silicon; there is modest attention being paid to this crucial aspect of design within BSN and WT in general. Considering that pervasive technology seeks long-term monitoring (when compared to laboratory settings or even hospital stays), the need for a well thought designed for testing strategy is a necessity. Not only the equipments and systems are expected to be reused by multiple individuals and therefore require of initialization and calibration mechanism, but due to the duration of the monitoring they also require of self-calibrating, self-testing, redundancy, and robustness. The trial or data gathering periods are now considerably longer, and therefore the data loss and impact of a failure in mid-examination has more consequences (due to the amount of data loss or the consequence to the health of the individual). Additionally, a significant portion of these systems are designed for injury prevention and medical diagnosis which makes the reliability of the systems an imperative. While an athlete's performance seems to have a lesser degree of concern, when considering system failures scenarios, it should be said that some of the designs seek (or are already designed for) "on-event" monitoring. Which means that the systems are expected to safeguard against injury and/or permit performance monitoring on real-time basis during life events (such as match, classificatory, etc), making their reliability a high priority as well.

Testing and design for testing is in itself an effort that has counted with the support of academy, industry and designers; which allowed for the formulation of several protocols that seek to alleviate the problems of accessibility and space within this increasingly complex scenario. Among the most known, and by no means the only ones, protocols for testing digital and analog interconnections and inter-module elements one finds the: IEEE 1149.1, 1149.4. 1149.6 and 1149.7, which will be briefly introduced.

A. *IEEE 1149.1 and 1149.7*

The 1149.1 represents the cornerstone of boundary-scan testing methodologies; introduced in 1990, it has taken 20 years for its replacement to arrive, the 1149.7. The 1149.1, also referred to as JTAG (Joint Test Action Group for the task force that proposed it), was originally intended for alleviating board-level interconnect testing complexity. Multi-layer board and increasing high density scenario left a reduced space for testing points and other traditional methods for interconnect testing. Nowadays, board-level and chip-level complexity is orders of magnitude higher, compare to the 90's, and yet the 1149.1 (which has undergone relatively small revision with the years) is still the workhorse of digital interconnect testing at board and chip level.

The 1149.1 takes advantage of a boundary-scan strategy, using an array of small modules, which intersect the data flowing through the IC pins. A small state machine, in combination with a reduced set of instructions and registers, permits controllability and observability to the input/output (I/O) of the IP cores and IC packages. The 1149.7 introduces a set of new testing and debugging features, divided in a class structure, while remaining backward compatible with the 1149.1. For a more in-depth understanding of these protocols we recommend the following literature (although there are literary hundreds of articles, books, and presentations on the subject of 1149.1, 1149.7 on the other hand is quite recent): (IEEE Std 1149.1-2001 , 2001) (Parker, 1998) (IEEE Std 1149.7-2009, 2010), (Ley, 2009).

B. *IEEE 1149.4 and 1149.6*

Analog and digital signals differ considerably in their testing requirements, as do their fault scenarios. Mixed-signal circuitry is becoming standard in most designs, particularly when WMS and BSN are considered. The 1149.4 and 1149.6 seek to address the challenges of mixed-signal design testing. The 1149.4 could be seen as an extension on the 1149.1 which offers "to improve the controllability and observability of mixed-signal designs and to support mixed-signal built-in test structures in order to reduce both test development time and testing costs and to improve test quality" (IEEE 1149.4-1999, 2000). On the other hand, the 1149.6 also extends the 1149.1 in order "to improve the ability for testing differential and/or ac-coupled interconnections between integrated circuits on circuit boards and systems" (IEEE Std 1149.6-2003 , 2003). So while 1149.4's modules allow us access to perform impedance measurement through the injection of current and/or voltage at strategic points, the 1149.6 concern's itself with the effects of increasingly faster clock frequency which are converting well-behaved digital signals into pseudo-analog forms which become more difficult to handle. As in the case of the 1149.1, there are a wide selection of articles, books, presentation and websites regarding these protocols, but the novice would be wise to start with: (Wang, et al., 2006) (Kim, et al., 2008) (National Semiconductor, 2004) (Eklow, et al., 2003).

V. Case Studies

It is clear that numerous systems have been and are being developed for monitoring patients, athletes and individuals in general, with a wide variation on the objectives. Some seeks to monitor biosignals for particular health conditions as a preventive manner, while other seeks to optimize the performance of an athlete, and yet others seek to avoid injuries and accidents among rescuers and fighters. Health-care has greatly benefitted from a large number of researches and products designed for prevention, monitoring and assist diagnosis; Dr. Pantelopoulos and Dr. Bourbakis published early this year a thorough survey of wearable sensor-based systems for health monitoring, where one can find a solid explanation of the common sections of the mentioned systems and study of what was referred to as the "state-of-the-art in research and development of wearable sensor-based systems" (Pantelopoulos, et al., 2010). In sports the reception to technology is not always a graceful one. Although it is true that most sports seem receptive to the contributions of science and research, the reality is that changes take place at a slow rate due to the acceptance of the athletes, coaches, venue owners (fields, courts, stadiums, sport complex, arenas, etc.), and the public in general (Chi, 2005). Although we have seen sports attires change with time (such as improved swimsuits, lighter and more efficient running shoes, special textile uniforms, etc.) and seen equipment change (such as bats, golf clubs, tennis racquets, etc.) the line between honorable improvement and unjust advantage is not always clear. Even in cases where technology was attempting to introduce fairness, such as the use of slow-motion repetitions or sensor based scoring systems, technology has sometimes been considered intrusive and unwelcomed. Dr. Winters related recently in a workshop that in year past his group came up with a design for a ballet shoe that avoided injury associated with dancing “en pointe”; to his surprise the shoe was not welcomed by dancers or the shoe industry. Some consulted dancers appreciations were that: “it did not feel right” (they claimed, as a negative issue, that the pain of position was no longer present); while the shoe industry seemed unimpressed by the design (which had the added bonus that did not wear as fast a regular ballet shoes). Where does technology stop being a contribution and becomes a hindrance to the purity of the game? It is because of this delicate balance that research in the area of sports monitoring must take an inclusive approach, involving the athletes, coaches and other individuals that are directly affected by the introduction of change. This said, it should be clear the advantages that a pervasive approach to sports monitoring has over conventional methodologies. Seamless technology could prove beneficial, strengthening the relations between coach and athletes, protecting beginners at the learning stages, avoiding injuries and contributing to a faster rehabilitation of the veteran athletes. Annex V contains a summary of projects and study cases where monitoring technology was applied with sports in mind (although the relation to sports is not all that clear for a few cases), from such table one can observe the international nature of this effort. Scientist and engineers of countries around the world are contributing to this field, which is still at the beginning stages of its development (especially when compared to the health-care centric cases).

Based on the information extracted from literature (in particular the cases summarized on Annex V), we can sum sports monitoring tendencies to the following the broad objectives:

- *Coaching assistance or Performance analysis*: although trainers are key elements in the tuning of an athlete’s skill; they have a limited perception of their performance. While a coach or trainer evaluates the actions of an athlete based on past experience and expertise, visual interpretation can only go so far. The incorporation of additional information, provided by accelerometers, pressure sensors, and other sensors, can serve to close the gap between an athlete’s self-perception and a trainer’s. The information gathered can also serve for fine-tuning the training regimen of an athlete’s, by correlating the data with performance results. Feature extraction methods and pattern recognition also grant the possibility for performance contrast and comparison among multiple individuals allowing for their classification (comparing a beginner’s performance to an advance athlete’s for example).
- *Injury prevention or Rehabilitation:* cyclic stress induced injuries, minor and major alike, are a common factor among most athletes; not to mention injuries cause by contact-sports, falling, or other sports associated accidents. WMT have proven a valuable asset in reducing the rehabilitation time and preventing injuries by allowing for the monitoring for aggravating factors and allowing for a continuous evaluation of the area of interest.
- *Unsupervised activity monitoring:* lifestyle considerations, of a large portion of the population, are cause for concern when considering chronic non-communicable diseases. Most physicians can only have a snap-shot assessment of a patient’s lifestyle, not to mention a very limited participation in the patient’s interpretation of the recommended course of action. We say interpretation since most patients are only given guidelines to follow when lifestyle habits are involved (such as dieting, exercise, and other lifestyle recommended changes). The mechanism for unsupervised activity monitoring benefits both patient and physician by introducing a closer connection between them, and permitting a more realistic determination of the daily activities of the individuals.
- *Stress/Fatigue evaluation:* within sports, stress and fatigue can cause an athlete’s performance to falter. An accurate determination of a individual’s stress/fatigue level could contribute to strategy decision making, in order to improve results.
- *Control mechanism:* technology has made a significant presence in most sports; so be it on the attire, the field/court or the equipment. For some time now exercise equipment has been augmented with electronics in order to improve performance and to reduce boredom (treadmills with consoles for playing poker for example). Nowadays virtual sports are gaining momentum, with such devices as the Nintendo Wii, Visual Sports and other sports simulators becoming commonplace items in most homes. In parallel, technology is transforming the way some matches scoring and judging occurs. Strike zone monitors, serve fault monitors, offside monitors are becoming more ordinary and almost mandatory equipment of some sports facilities. The next step of scoring and/or referee assistance technology can be seen on some wearable monitoring devices.

VI. Proposal

A simple design for a wearable monitoring module and communication module is hereby presented. The design, as seen on Figure 2, has for main components:

- Microcontroller CC430F5137IRGZR
- Microcontroller MSP430F2121
- MicroSD slot
- TI CC2590

The components were chosen based on avalability, cost, ease of use, available documentation, and other factors. It should be mentioned that alternatives to the chosen components as are valid, and might be preferable, depending on the location and nature of the research. While the design thrives to be efficient and compact, preference was allocated to performance and local data storing (hence the microSD card slot), at this stage of the project. The design was thought more as a universal monitoring module, than a “mote” design, based on ideas provided by existing alternatives and past research (information found within all Annex) (Cumming, et al., 2006) (Salazar, et al., 2005) (Salazar, et al., 2006).

One might argue that two microcontrollers are excesive and power consuming; however this proposal seeks a more acommodating design, where numerous sensor types and situation can be serviced. The additional microcontroller is focused on the transmission, storing and other communication requirements (JTAG, UART, etc.) the module might need; while the remaining microcontroller is dedicated to sensor capturing and processing, thus introducing some parallel processing capabilities through the shared links (although of limited nature). A FPGA was initial thought for handling most og the functionality, providing true parallel capabilities and custom functional design. However it was consider excesive for a first prototype, since the learning curve and added board complexity would delay the adquisition timeline.

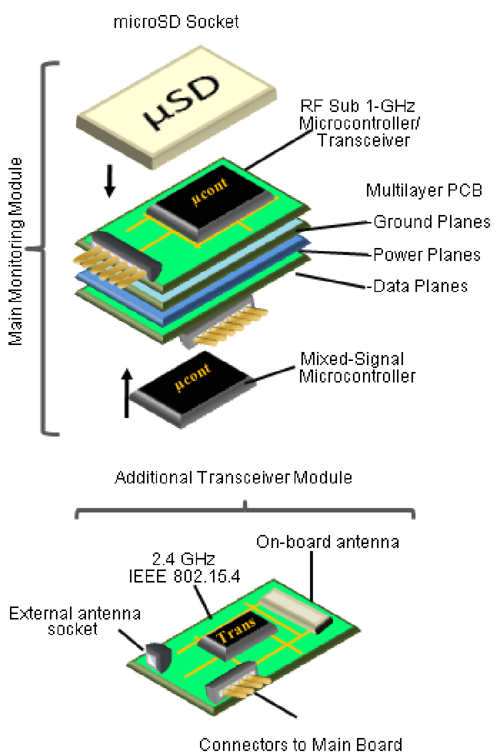

Figure 2. Monitoring system proposal

The additional transceiver module was consider for particular cases, such as aquatic sports; where the need for a separate communication module is aparrent, so as to position the module on a strategic location or perhaps floating independently.

VII. 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 the truth behind an athlete execution; it is also providing mechanisms for insuring their safety from injury and long term ailments. WMT 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. In spite of such advancement it is clear that a number of obstacles remain to be contended with, such as energy consumption and self maintainability; and although there are numerous individuals involved in the research and development of the first, only a limited number of efforts are being focus on the later. Testing and self configurability presents themselves as bottleneck not only within the IC industry, but in the age of mixed signal, nanostructures and ever more complex hybrid systems and module integration, they have become an unquestionable necessity. This article attempted to present the reader with the current scenario for the design and development of wearable monitoring solutions, focused on sports (as opposed to healthcare, even though both share a significant number of common elements). 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 could be used for monitoring (or even control applications); such solution is a first attempt and will undoubtedly change with the continuous new offers in the commercial component market.

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References

Akyildiz I.F. [et al.] Wireless Sensor Networks: a survey [Journal]. - [s.l.] : Elsevier, 2002. - Vol. 38.

Albus Zack, Valenzuela Adrian and Buccini Mark Ultra-Low Power Comparison: MSP430 vs. Microchip XLP Tech Brief [White Paper SLAY015]. - [s.l.] : Texas Instrument, October 2009.

Altera Corporation Stratix Series FPGA Low Power Consumption Features [Online] // FPGA, CPLD and ASIC from Altera. - Altera Corporation, 2010. - 2010. - http://www.altera.com/products/devices/stratix-fpgas/stratix-iv/overview/power/stxiv-power.html?GSA_pos=1&WT.oss_r=1&WT.oss=low power fpga.

AVR XMEGA; Rev.: 7925C-AVR-10/08/10M [7925C-AVR-10/08/10M]. - [s.l.] : Atmel, 2008.

Aziz Omer [et al.] Introduction [Book Section] // Body Sensor Networks / ed. Yang Guang-Zhong. - London : Springer Verlag, 2006.

Bleecker Julian [et al.] Mobzombies: A Wearable sensor for a playground style electronic game [Conference] // 11th IEEE International Symposium on Wearable Computers. - Boston, MA, USA : IEEE, 2007.

Bonato Paolo [et al.] IEEE EMBS Technical Committee on Wearable Biomedical Sensors & Systems: Position Paper [Conference] // Proceedings of the International Workshop on Wearable and Implantable Body Sensor Networks (BSN'06). - Boston, USA : IEEE, 2006. - Vols. 0-7695-2547-4/06.

Borges Luis M. [et al.] Overview of Progress in Smart-Clothing Project for Health Monitoring and Sport Applications [Conference] // First International Symposium on Applied Sciences in Biomedical and Communication Technologies. - Aalborg, Denmark : IEEE, 2008.

Borges Luis M. [et al.] Smart-Clothing Wireless Flex Sensor Belt Network for Foetal Health Monitoring [Conference] // 3rd International Conference on Pervasive Computing Technologies for Healthcare 2009. - London, UK : IEEE, 2009.

Brown J. Q., Srivastava R. and McShane M. J. Encapsulation of glucose oxidase and an oxygen-quenched flurophore in polyelectrolyte-coated calcium alginate microshepres as optical glucose sensor systems [Journal] // Biosensors and Bioelectronics. - [s.l.] : Elsevier, 2005. - 1 : Vol. 21.

Cheng L. and Haile S. Managed exercise monitoring: a novel application of wireless on-body inertial sensing [Conference] // 5th Inenational Summer School and Symposium on Medical Devices and Biosensors. - [s.l.] : IEEE, 2008.

Cheng L. and Hailes S. Analysis of Wireless Inertial Sensing for Athlete Coaching Support [Conference] // IEEE Global Telecommunications Conference. - [s.l.] : IEEE, 2008.

Chi E. H. Introducing wearable force sensors in martial arts [Journal]. - [s.l.] : IEEE Journals, 2005. - 3 : Vol. 4.

Connaghan D. [et al.] A Sensing Platform for Physiological and Contextual Feedback to Tennis Athletes [Conference] // Sixth International Workshop on Wearable and Implantable Body Sensor Networks,. - [s.l.] : IEEE Conferences, 2009.

Coyle S. [et al.] BIOTEX—Biosensing Textiles for Personalised Healthcare Management [Journal] // IEEE Transactions on Information Technology in Biomedicine. - [s.l.] : IEEE Transactions, 2010. - 2 : Vol. 14.

Cumming David R.S. [et al.] Wireless Sensor Microsystem Design: Practical Perspective [Book Section] // Body Sensor Networks / ed. Yang Guang-Zhong. - London, UK : Springer-Verlag, 2006.

Cunha Joao P. Silva [et al.] Vital-Jacket®: A wearable wireless vital signs monitor for patients' mobility in cardiology and sports [Conference] // 4th International Conference on Pervasive Computing Technologies for Healthcare (PervasiveHealth). - [s.l.] : IEEE, 2010.

Dewei Jia and Jing Liu Human power-based energy harvesting strategies for mobile electronic devices [Journal] // Frontiers of Energy and Power Engineering in China. - [s.l.] : Higher Education Press, co-published with Springer-Verlag GmbH, 2009. - 1 : Vol. 3.

Dillard W. [et al.] Issues in wearable biomechanical inertial sensor systems [Conference] // IEEE/ION Position, Location and Navigation Symposium. - [s.l.] : IEEE Conferences, 2008.

Eklow B., Parker K.P. and Barnhart C.F. IEEE 1149.6: a boundary-scan standard for advanced digital networks [Conference] // IEEE Design and Test of Computers. - [s.l.] : IEEE Conferences, 2003.

EMBS Technical Committee on Wearable Biomedical Sensors and Systems: Home [Online] // Technical Committee on Wearable Biomedical Sensors and Systems. - Engineering in Medicine and Biology Society, 2008. - 03 24, 2010. - http://tc-wearable-sensors.embs.org/index.html.

Ermes M. [et al.] Detection of Daily Activities and Sports With Wearable Sensors in Controlled and Uncontrolled Conditions [Journal] // IEEE Transactions on Information Technology in Biomedicine. - [s.l.] : IEEE Journals, 2008. - 1 : Vol. 12.

Glaros C. [et al.] A wearable intelligent system for monitoring health condition and rehabilitation of runing atheletes [Conference] // 4th Annual IEEE Conference on Information Technology Application in Biomedicine. - UK : IEEE, 2003.

Heile Bob IEEE 802.15 Working Group for WPAN [Online] // IEEE802 / ed. Bob Heile email: bheile@ieee.org. - IEEE, May 23, 2010. - 2010. - http://www.ieee802.org/15/. - Contact (alfvin@ieee.org).

Heinz Enst A. [et al.] Using Wearable Sensors for Real-Time Recognition Tasks in Games of Martial Arts - An Initial Experiment [Conference] // 2006 IEEE Symposium on Computational Intelligence and Games. - Lake Tahoe, NV, USA : IEEE, 2006.

Higgins Henry Wireless Communication [Book Section] // Body Sensor Networks / ed. Yang Guang-Zhong. - London, UK : Springer-Verlag, 2006.

Holleczek T. [et al.] Towards an Interactive Snowboarding Assistance System [Conference] // International Symposium on Wearable Computers. - [s.l.] : IEEE Conferences, 2009.

IEEE 1149.4-1999 IEEE Standard for a Mixed-Signal Test Bus [Report]. - [s.l.] : IEEE Standards, 2000.

IEEE Std 1149.1-2001 IEEE Standard Test Access Port and Boundary-Scan Architecture [Report]. - [s.l.] : IEEE Standards, 2001.

IEEE Std 1149.6-2003 IEEE Standard for Boundary-Scan Testing of Advanced Digital Networks [Report]. - [s.l.] : IEEE Standards, 2003.

IEEE Std 1149.7-2009 IEEE Standard for Reduced-Pin and Enhanced-Functionality Test Access Port and Boundary-Scan Architecture [Report]. - [s.l.] : IEEE Standards, 2010.

Imote2: High-performance Wireless Sensor Network Node. - [s.l.] : Crossbow. - Vols. 6020-0117-02 Rev A.

IRIS: Wireless measurement system. - [s.l.] : Crossbow. - Vols. 6020-0124-01 Rev A.

Kephart J.O. and Chess D.M. The vision of autonomic computing [Journal] // Computer. - [s.l.] : IEEE Journals, 2003. - 1 : Vol. 36.

Khan Qadeer and Bang Sarvesh Energy harvesting for self-powered wearable health monitoring system [Online] // EE Times Europe Analgo. - April 9, 2009. - 2010. - http://www.analog-europe.com/en/energy-harvesting-for-self-powered-wearable-health-monitoring-system.html?cmp_id=7&news_id=221901075.

Kim Bruce C. [et al.] Low cost automatic mixed-signal board test using IEEE 1149.4 [Conference] // IEEE International Test Conference. - [s.l.] : IEEE Conferences, 2008.

Knight James H. [et al.] The design of the SensVest [Journal] // Persavise Ubiquitous Computing 9: 6–19. - London, UK : Springer-Verlag, 2005.

Ley A.W. Doing more with less - An IEEE 1149.7 embedded tutorial : Standard for reduced-pin and enhanced-functionality test access port and boundary-scan architecture [Conference] // International Test Conference. - [s.l.] : IEEE Conferences, 2009.

Lo Benny and Yang Guang-Zhong Architecture for Body Sensor Networks [Conference] // Conference on Perspective in Pervasive Computing. - 2005.

Lo Benny and Yang Guang-Zhong Body Sensor Networks: Infrastructure for Life Science Sensing Research [Conference] // IEEE/NLM Life Science Systems and Applications Workshop. - [s.l.] : IEEE Conferences, 2006.

Lo Benny and Yang Guang-Zhong Source Recovery for Body Sensor Networks [Conference] // IEEE Proceeding of Body Sensor Networks. - [s.l.] : IEEE Conferences, 2006.

Lo Benny P.L. and Yang Guang-Zhong Body Sensor Networks - Research Challenges and Opportunities [Conference] // IET Seminar on Antennas and Propagation for Body-Centric Wireless Communications. - [s.l.] : IEEE, 2007.

Lo Benny P.L. and Yang Guang-Zhong Key Technical challenges and current implementations of Body Sensor Networks [Conference] // 2nd International Workshop on Body Sensor Networks. - London, UK : IEE Proceedings, 2005.

Lorinxz Konrad [et al.] Wearable Wireless Sensor Network to Assess Clinical Status in Patients with Neurological Disorders [Conference] // International Conference on Information Processing in Sensor Networks. - Cambridge, MA, USA : [s.n.], 2007.

Madni Jamal A. and Lee Juo-Yu Processing Biometric Data of Game Players using Body Sensors [Conference] // IEEE Sensors Applications Symposium. - New Orleans, USA : IEEE Conference, 2009.

Maher M. P. [et al.] The neurochip: a new multielectrode device for stimulating and recording from cultured neurons [Journal] // Journal of Neuroscience Methods. - Netherlands : Elsevier/North-Holland Biomedical Press, 1999. - 7 : Vol. 87.

Mars Pierre Managing the power in wireless sensor networks powered by energy-harvesting circuitry [Online] // RF Designline. - RF Designline, 06 07, 2010. - 2010. - http://www.rfdesignline.com/howto/225400098.

Matsushita Soichiro, Shiba Ayumi and Nagashima Kan A Wearable Fatigue Monitoring System - Application of Human-Computer Interaction Evaluation [Conference] // Seventh Australasian User Interface Conference. Conferences in Research and Practice in Inforamtion Technology. - Hobart, Australia : [s.n.], 2006. - Vol. Vol. 50..

MICAz: Wireless Measure System. - [s.l.] : Crossbow. - Vols. 6020-0060-04 Rev A.

Michahelles Florian and Schiele Bernt Sensing and Monitoring Professional Skiers [Journal] // Pervasive Computing. - [s.l.] : IEEE CS and IEEE ComSoc, July-September 2005. - 3 : Vol. 4. - pp. 40-46.

Mitchell Mike Choosing An Ultralow-Power MCU [SLAA207] = Application Report. - [s.l.] : Texas Instrument, June 2004.

Morris D. [et al.] Wearable Sensors for Monitoring Sports Performance and Training [Conference] // 5th International Summer School and Symposium on Medical Devices and Biosensors. - [s.l.] : IEEE Conferences, 2008.

NanoWatt XLP eXtreme Low Power MCUs [Datasheet, DS39941C]. - [s.l.] : Microchip, November 2009.

National Semiconductor Mixed Signal Testing Using the IEEE 1149.4 STA400. - [s.l.] : National Semiconductor, 2004.

Pansiot Julien [et al.] ClimBSN: Climber Performance Monitoring with BSN [Conference] // 5th International Workshop on Wearable and Implantable Body Sensor Networks,. - Hong Kong, China : IEEE, 2008.

Pantelopoulos Alexandros and Bourbakis Nikolaos G. A survey on wearable sensor-based systems for health monitoring and prognosis [Journal] // IEEE transactions on systems, man and cybernetics. - [s.l.] : IEEE, 2010. - 1 : Vol. 40.

Parker K. The boundary-csan handbook: analog and digital [Book]. - [s.l.] : Kluwer Academic Press, 1998. - Vol. 2nd rev..

Patel Bhavik A., Anastassiou Costa A. and O'Hare Danny Biosensor Design and Interfacing [Book Section] // Body Sensor Networks / ed. Yang Guang-Zhong. - London : Sprigner Verlag, 2006.

Pistoia Gianfranco Baterry operated Devices and Systems [Book]. - Amsterdam, The Netherlands : Elsevier B.V., 2009.

Rocha L.A. and Correia J.H. Wearable Sensor Network for Body Kinematics Monitoring [Conference] // 10th IEEE International Symposium on Wearable Computers,. - [s.l.] : IEEE Conferences, 2006.

Salazar A. J. and Bravo R. J. Managing EMG signals for control strategies for a Multi-Functional Interface for Patients with Severe Motor Disabilities [Conference] // The International Special Topic Conference on Information Technology in Biomedicine. - Ioannina, Greece : [s.n.], 2006.

Salazar A. J., Bravo R. J. and Ponticelli D. Hybrid Multi-Source, Multi-Function Patient Adaptable System for Assistive Technology Control Applications [Conference] // 3rd European Medical and Biological Engineering Conference. European Conference on Biomedical Engineering. - Prague, Czech Republic : IFMBE Proceedings, 2005.

Schmid Thomas [et al.] Movement Analysis in Rock-Climbers [Conference] // International Conference in Information Processing in Sensor Networks. - Cambridge, MA, USA : ACM, 2007.

Surapa Thiemjarus, Benny Lo and Guang-Zhong Yang Perspective in Pervasive Computing [Conference] // IEE Proceedings of the Perspective in Pervasive Computing. - [s.l.] : IEE Conferences, 2005.

TELOSB: TELOSB mote platform. - [s.l.] : Crossbow. - Vols. 6020-0094-01 Rev B.

Tesconi M. [et al.] Wearable sensorized system for analyzing the lower limb movement during rowing activity [Conference] // IEEE International Symposium on Industrial Electronics. - Vigo, Spain : IEEE, 2007.

Texas Instrument Low Power RF Protocols - ZigBee-CC2420 - TI.com [Online] // Analog, Embedded Processing, Semiconductor Company, Texas Intruments. - Texas Instruments, 2007. - 2010. - http://focus.ti.com/docs/prod/folders/print/cc2420.html.

Tufail Farhana and Islam Hassan Wearable Wireless Body Area Networks [Conference] // International Conference on

Information Management and Engineering. - Kuala Lumpur, Malaysia : IEEE, 2009.

Van Laerhoven Kristof [et al.] Medical Healthcare Monitoring with Wearble and Implantable Sensors [Conference] // 3rd International Workshop on Ubiquitous Computing for Healthcare Applications. - 2004.

Venkatasubramanian K. and Gupta S. K. Ayushman: a secure, usable pervasive health monitoring system [Conference] // Proceedings of the 2nd International Workshop on Systems and Networking Support for Health Care and Assisted Living Environments. - [s.l.] : ACM, 2008.

Wang Laung-Terng, Wu Cheng-Wen and Wen Xiaoqing VLSI Test Principles and Architectures: Design for Testability (Systems on Silicon) [Book]. - [s.l.] : Morgan Kaufmann, 2006.

Warneke B. [et al.] Smart Dust: communicating with a cubic-millimeter computer [Journal] // Computer. - [s.l.] : IEEE, 2001. - 1 : Vol. 34.

Warneke B., Atwood B. and Pister K.S.J. Smart dust mote forerunners [Conference] // 14th IEEE International Conference on Micro Electro Mechanical Systems. - [s.l.] : IEEE, 2001.

Xilinx Inc. Power Solutions: Information and tools for conquering the key challenges of power consumption [Online] // FPGA solutions from Xilinx, Inc.. - Xilinx Inc., 2010. - 2010. - http://www.xilinx.com/products/design_resources/power_central/.

Yang Guang-Zhong Body Sensor Networks [Book]. - [s.l.] : Springer, 2006.

Yang Guang-Zhong Sports body sensor networks [Conference] // International Summer School and Symposium on Medical Devices and Biosensors. - Hong Kong : IEEE, 2008.

Yang Guang-Zhong, Lo Benny and Thiemjarus Surapa Autonomic Sensing [Book Section] // Body Sensor Networks / ed. Yang Guang-Zhong. - [s.l.] : Springer-Verlag, 2006.

Yang Guang-Zhong, Lo Benny P.L. and Thiemjarus S Autonomic Sensing [Book Section] // Body Sensor Networks / ed. Yang Guang-Zhong. - London : Springer Verlag, 2006.

Yang Liu and Shouqian Sun Smart Sport Underwear Design [Conference] // 7th International Conference on Computer-Aided Industrial Design and Conceptual Design. - Hangzhou, China : IEEE, 2006.

ANNEX I

Feature Comparison of Most Popular Commercially Available Motes Modules for Wireless Monitoring Systems (Part 1)

Mote	Model	Processor	Wireless	Antenna/ Range	Memory/ Storage	Features	Software	Power Supply
Imote2	IPR2400	Intel PXA271 XScale CPU	TI CC2420 IEEE 802.15.4, 250kb/s data rate, 16 ch.	2.4GHz surface mount antenna. Range: 30m	256kB SRAM, 32MB SDRAM and 32MB of FLASH	I2C, 2 SPI (one dedicated to radio), 3 high speed UARTs, GPIOs, SDIO, USB client and host, AC97 and I2S audio codec interfaces, a fast infrared port, PWM, Camera Interface, high speed bus (Mobile Scaleable Link). Multiple timers and a RTC. 30 new media processor (DSP) instructions, support for alignment and video operations and compatibility with Intel MMX and SSE integer instructions	TinyOS	3xAAA batteries Voltage 3.2 – 4.5 V, Li-Ion or Li-Poly batteries, USB
IRIS 2.4 GHz	XM2110CA	Atmel ATmega128L	2.4 GHz IEEE 802.15.4, 250 kbps data rate	2.4GHz 1/4 wave dipole antenna, LOS. Range: > 300m (outdoor) > 50m (indoor)	Program Flash Memory 128KB, Measurement (Serial) Flash 512KB, RAM 8KB, Configuration EEPROM 4KB	Digital I/O,I2C,SPI, 10 bit A/D 8 channel, 0-3V input, UART 0-3V transmission levels	MoteWorks (based on TinyOS)	2xAA batteries External Power 2.7 V - 3.3 V

Feature Comparison of Most Popular Commercially Available Motes Modules for Wireless Monitoring Systems (Part 2)

Mote	Model	Processor	Wireless	Antenna/ Range	Memory/ Storage	Features	Software	Power Supply
MICAz 2.4 GHz	MPR2400	Atmel ATmega128L	2.4 GHz IEEE 802.15.4, 250 kbps data rate	2.4GHz 1/2 wave dipole antenna, LOS. Range: 75 m to 100 m (outdoor), 20 m to 30 m (indoor)	Program Flash Memory 128KB, Measurement (Serial) Flash 512KB, Configuration EEPROM 4KB	Digital I/O,I2C,SPI, 10 bit A/D 8 ch., 0-3V input, Serial Comm. UART 0-3V TX levels	MoteWorks (based on TinyOS)	2xAA batteries, External Power 2.7 V - 3.3 V
TelosB	TPR2400	TI MSP430	2.4 GHz IEEE 802.15.4, 250 kbps data rate	2.4GHz Inverted-F antenna. Range: 75 m to 100 m (outdoor), 20 m to 30 m (indoor)	Program Flash Memory 48KB, Measurement (Serial) Flash 1024KB, RAM 10KB, Configuration EEPROM 16KB	Digital I/O,I2C,SPI, 12 bit DAC 2 ports, 12 bit A/D 8 ch., 0-3V input, UART 0-3V TX levels	TinyOS 1.1.10 or higher	2xAA batteries, USB v1.1 or higher
Shimmer	SH-SHIM-KIT-001	TI MSP430	TI CC2420 IEEE 802.15.4, 250kb/s data rate, 16 ch.		Program Flash Memory 48KB, RAM 10KB, SD card (2GB)	Digital I/O,I2C,SPI, 8 ch. of 12 bit A/D, 3D MEMS acc., Freescale MMA7260Q, Bluetooth radio, Integrated TCP/IP stack for 802.15.4, Integ. tilt / vibration sensor, Integ. Li-ion battery manag.	TinyOS 1.1.15 or higher	280mAh Li-On Battery

Data extracted:
Crossbow datasheet: TelosB, MICAz 2.4 GHZ, IRIS 2.4 GHz, Imote2
SHIMER. http://www.shimmer-research.com/p/products/sensor-units-and-modules/shimmer-wireless-sensor-unitplatform

Annex II

Catalog of Sensors Designers and Manufacturers (Part 1/4)

Company	Sensor Type	Website	Comment
Advanced Photonix Inc.	OSMe	www.advancedphotonix.com	Optoelectronic solutions and Tetrahertz instrum.
Analog Devices	AGISoT	www.analog.com	Analog, mixed-signal, and digital signal processing (DSP) integrated circuits (IC)
Atmel	To	www.atmel.com	Microcontroller, capacitive touch solutions, advanced logic, mixed-signal, nonvolatile memory and radio frequency (RF) componen
Avago Technologies	OS	www.avagotech.com	Log, mixed-signal and optoelectronic components and subsystems
B & L Engineering	B	www.bleng.com	Designs, manufactures, and sells Gait Analysis Equipment, Pinch Gauges and Scoop Dishes.
Biometrics Ltd	B	www.biometricsltd.com	Design, manufacture and distribution of technologically advanced sensors, instruments and software for the demanding needs in biomedical and engineering research, clinical rehabilitation and educational settings
Bosch Sensortec	AAnPMe	www.bosch-sensortec.com	Ranging from pressure and acceleration to yaw sensors
Bourns	AnMPo	www.bourns.com	Precision potentiometers, panel controls, encoders, resistor/capacitor networks, network interface devices, and integrated circuits
Clare	MSol	www.clare.com	High-voltage integrated circuits (ICs) and optically isolated Solid State Relays
CR Magnetics	M	www.crmagnetics.com	Products to monitor any group or individual power-using equipment
CUI Inc.	ST	www.cui.com	Electro-mechanical components for the OEM manufacturer
Curtis Instruments Inc.	P	curtisinstruments.com	Wide range of instrumentation, controls, and integrated systems for all types of applications
Delsys	B	www.delsys.com	Parallel bar EMG sensor and other biosignal sensors
Digi International	AMltS	www.digi.com	Products and technologies for securely managing local or remote electronic devices over a network or via the Internet
DLP Design	AT	www.dlpdesign.com	Hardware and software solutions to interface to a host computer via the USB interface

A: accelerometer, An: angle sensor, B: biosignals, C: color sensor, D: distance, F: force sensor, G: Gyroscope, I: inertial sensor, In: inclinometer, L: light sensor, M: magnetometer, Me: MEMs, Mlt: multifunction, O: optical, P: pressure sensor, Po: position sensor, R: rotational sensor, S: specialized, So: sound, Sol: solar, T: temperature sensor, To: touch sensor

Annex II

Catalog of Sensors Designers and Manufacturers (Part 2/4)

Company	Sensor Type	Website	Comment
EPCOS Inc.	PT	www.epcos.com	Manufactures and markets electronic components, modules and systems, SAW components, ceramic components, capacitors and inductors
Freescale Semiconductor	ABPTo	www.freescale.com	Power management solutions, microprocessors, microcontrollers, sensors, radio frequency semiconductors, analog and mixed signal circuits and software technologies
GE Sensing	MltPT	www.gesensing.com	Provides sensing elements, devices, instruments, and systems that enable our customers to monitor, protect, control, and validate their critical processes and applications
Honeywell Microelectronics and Precision Sensors	MPT	www.ssec.honeywell.com	Radiation Hardened Electronics, magnetic sensors, pressure transducers, high temperature electronics, microwave products
Honeywell Sensing and Control	BFMPPoT	sensing.honeywell.com	50,000 products ranging from snap action, limit, toggle and pressure switches to position, speed and airflow sensors
Infineon Technologies	MPSo	www.infineon.com	Leading-edge technology in analog and mixed signal, RF and power as well as embedded control.
Intersil	LP	www.intersil.com	Specializing in the design and manufacture of high performance analog semiconductors.
InvenSense	Gme	invensense.com	MEMS gyroscopes for motion processing solutions in consumer electronics
IXYS	Sol	www.ixys.com	Power semiconductors for solar/wind energy conversion, and introduced the first solar cell for charging portable batteries.
Measurement Specialities Inc.	BFMePPoT	www.meas-spec.com	Global designer and manufacturer of sensors and sensor-based systems which measure pressure/force, position, vibration, temperature, humidity, and fluid properties
Mega Electronics Ltd	B	www.megaemg.com	Specialized in biosignals monitoring for neurology, rehabilitation, occupational health, sports medicine and gynecology
Melexis	IMOP	www.melexis.com	Manufacture and deliver advanced Mixed Signal semiconductors, sensor ICs, and programmable sensor IC systems for the automotive industry Bottom of Form

A: accelerometer, An: angle sensor, B: biosignals, C: color sensor, D: distance, F: force sensor, G: Gyroscope, I: inertial sensor, In: inclinometer, L: light sensor, M: magnetometer, Me: MEMs, Mlt: multifunction, O: optical, P: pressure sensor, Po: position sensor, R: rotational sensor, S: specialized, So: sound, Sol: solar, T: temperature sensor, To: touch sensor

Annex II

Catalog of Sensors Designers and Manufacturers (Part 3/4)

Company	Sensor Type	Website	Comment
Mind Media B.V.	B	www.mindmedia.nl	Specializes in physiological monitoring & feedback products and solutions for researchers, clinicians and health professionals
Murata Electronics	AAnMT	www.murata.com	Developed a range of sensing technologies that can detect heat, infrared, ultrasonic waves, vibration, acceleration, angular velocity, angular rotation, rotation, magnetism and electrical fields.
NexGen Ergonomics	B	www.nexgenergo.com	Leading worldwide source for software and instrumentation used in ergonomics and biomechanics for analysis, research, design and education.
NXP Semiconductors	AnRT	www.nxp.com	Provides High Performance Mixed Signal and Standard Product solutions that leverage its leading RF, Analog, Power Management, Interface, Security and Digital Processing expertise
Omron Electronics	BOR	ww.omron.com	Sensing and control electronics
Onset Computer Corp	AAnPT	www.onsetcomp.com	Leading supplier of data loggers
Panasonic	AnCOP	pewa.panasonic.com	Carries the SUNX Line of Sensors and Laser Makers, product lines manufactured by our close corporate affiliate, SUNX Ltd.
Parallax Inc.	AAnCLMPT	www.parallax.com	BASIC Stamp microcontrollers and development software, SX chips and programmers/debuggers, Propeller chips and tools, project boards, robotics kits, educational tools, and sensors.
Qubit Systems	B	www.qubitsystems.com	Design of instrumentation for research and teaching in the biological sciences, with a scope ranging from plant physiology to human respirometry
SANYO Semiconductor	OSol	semicon.sanyo.com	Resource-saving ultra-small transistors, unique hard-wired logic ICs and thick film ICs, which contribute to the miniaturization and the reduction in power consumption of electronic devices
Senstronics LTD	P	www.senstronics.com	High stability range of pressure sensing products
Sharp Microelectronics	D	www.sharpsme.com	Product range includes the latest, smallest, brightest LCDs with the widest viewing angles, Optoelectronics for highly efficient sensing and power management, Flash and Stacked Chip Memory for size and cost efficiency, tiny Imagers that pack more pixel-power in a smaller space, and our System-on-Chip devices to incorporate popular peripheral devices with a power-efficient processor

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Annex II

Catalog of Sensors Designers and Manufacturers (Part 4/4)

Company	Sensor Type	Website	Comment
Qubit Systems	B	www.qubitsystems.com	Design of instrumentation for research and teaching in the biological sciences, with a scope ranging from plant physiology to human respirometry
SANYO Semiconductor	OSol	semicon.sanyo.com	Resource-saving ultra-small transistors, unique hard-wired logic ICs and thick film ICs, which contribute to the miniaturization and the reduction in power consumption of electronic devices
Senstronics LTD	P	www.senstronics.com	High stability range of pressure sensing products
Sharp Microelectronics	D	www.sharpsme.com	Product range includes the latest, smallest, brightest LCDs with the widest viewing angles, Optoelectronics for highly efficient sensing and power management, Flash and Stacked Chip Memory for size and cost efficiency, tiny Imagers that pack more pixel-power in a smaller space, and our System-on-Chip devices to incorporate popular peripheral devices with a power-efficient processor
Shimmer Research	B	www.shimmer-research.com	A wearable sensor, Shimmer incorporates wireless ECG, EMG, GSR, Accelerometer, Gyro, PIR, Tilt and Vibration sensors.
Spectra Symbol	BMPoT	www.spectrasymbol.com	Designs and manufactures custom linear potentiometers. Their position sensors are specially designed for use in medical, automotive and electronic industries
SSI Technologies Inc	PM	www.ssitechnologies.com	Designs and manufactures pressure, level and magnetic sensors, sensor-based monitoring systems, digital pressure gauges, digital level gauges and powdered-metal components for automotive and industrial applications
STMicroelectronics	ACGIMMeTTo	www.st.com	Sensors that make electronic devices sensitive to motion, touch, proximity, color and temperature.
VTI Technologies	AAnBGMePT	www.vti.fi	Leading designer and manufacturer of silicon capacitive acceleration and pressure sensors

A: accelerometer, An: angle sensor, B: biosignals, C: color sensor, D: distance, F: force sensor, G: Gyroscope, I: inertial sensor, In: inclinometer, L: light sensor, M: magnetometer, Me: MEMs, Mlt: multifunction, O: optical, P: pressure sensor, Po: position sensor, R: rotational sensor, S: specialized, So: sound, Sol: solar, T: temperature sensor, To: touch sensor

Annex III

Energy consumption comparison of most popular commercially available Microcontrollers Series for Wireless Monitoring Systems

Processor	Manuf.	Arch.	Active Mode Current	Sleep Current	RTC	WDT	BOR
PIC MCUs with nanowatt XLP (eXtreme Low Power)	Microchip	8bit - 16bit	> 50uA/MHz	> 20 nA	> 200nA	> 200nA	> 45nA
MSP430™16-bit Ultra-Low Power MCUs	Texas Instrument	16bit	> 200uA @ 1MHz	>500 nA	> 1uA	> 300 nA	(10 - 70) uA
Ultra-low Power picoPower AVR MCU	Atmel	8bit - 16bit	> 340uA	>100 nA	> 650 nA		>20uA

Manuf.: Manufacturer; Arch.: Architecture; RTC: Real-time Clock; WDT: Watch-Dog Timer; BOR: Brown-out Reset

Data extracted from:

Texas Instrument:

MSP430™ - The World's Lowest Power MCU http://focus.ti.com/mcu/docs/mcuorphan.tsp?contentId=61835&DCMP=MSP430&HQS=Other+OT+ulp

TI Application Report SLAA207. Mike Mitchell. Choosing An Ultralow-Power MCU. June 2004

TI White Paper. Albus, Zack; Valenzuela, Adrian; Buccini, Mark. Ultra-Low Power Comparison: MSP430 vs. Microchip XLP Tech Brief. October 2009

Atmel:

Atmel - Atmel Expands its Ultra-low Power Microcontroller Offering with Three New picoPower AVR MCU's
http://www.atmel.com/dyn/products/view_detail.asp?ref=&FileName=megafamily_9_13.html&Family_id=607

Atmel – AVR Solutions – Devices http://www.atmel.com/dyn/products/devices_v2.asp?family_id=607#1603

Atmel. AVR XMEGA: 8/16-bit High Performance Low Power Flash Microcontrollers. Rev.: 7925C-AVR-10/08/10M, 2008.

Atmel. AVR 1310: Using the XMEGA Watchdog Timer. 8034B-AVR-04/09, 2009.

Microchip

Microchip - eXtreme Low Power: http://www.microchip.com/en_us/technology/xlp/

Annex IV

Feature Comparison of commercially available RF transceiver solutions

Transceiver	Manuf.	TX (dBm)	TX (mA)	RX (mA)	Sensitivity (dBm)	Frequency Range	Standard
CC2400	Texas Instruments	0	19	24	-87 - 101	2400-2483,5 MHz 1MHz steps	2.4 GHz ISM Band
CC2420	Texas Instruments	0	19,7	17,4	-95	2400-2483,5 MHz 1MHz steps	2,4 GHz IEEE 802.15.4
CC2520	Texas Instruments	0	25,8	18,8 22,3	-98	2394-2507 MHz 1MHz steps	2,4 GHz IEEE 802.15.4
MRF24WB0MA	Microchip	0	115	85	-85	2412-2484 MHz 1MHz steps	2.4 GHz, IEEE Std. 802.11b
MRF49XA	Microchip	0	15	11	-110	ISM Band 433, 868, 915 MHz	Proprietary Sub-GHz Wireless Protocols
UZ2400	Bubec	0	22	18	-95	2405-2480 MHz	2,4 GHz IEEE 802.15.4
MAX2830	Maxim	17,1 - 20,3	82	62	-75	2400 - 2500 MHz	IEEE 802.11g/b Compatible
AT86RF212	Atmel	0	13	9,2	-93 to -110	Chinese WPAN 779 - 787 MHz European SRD 863 - 870 MHz N.American ISM 902 - 928 MHz	IEEE 802.15.4 and 4c
XE1203F	Semtech	0 - 15	62 @ 15dBm	14	-96 to -114	ISM Band 433, 868, 915 MHz	
SX1212	Semtech	1-10	25 @ 10dBm, 16 @ 1dBm	3	-104 to -110	300MHz to 510MHz	
nRF2401A	Nordic	-5 – 0	10.5 @ -5dBm	18	-93	2.4 - 2.5 GHz ISM	

Values present at table correspond to typical measurements. Data extracted directly from datasheets of each product found at the following website locations:

http://www.ubec.com.tw/product/uz2400.html
http://www.maxim-ic.com/quick_view2.cfm/qv_pk/5367
http://www.atmel.com/dyn/resources/prod_documents/doc8168.pdf
http://focus.ti.com/docs/prod/folders/print/cc2400.html
http://www.nordicsemi.com/index.cfm?obj=product&act=display&pro=64#
http://focus.ti.com/docs/prod/folders/print/cc2420.html
http://focus.ti.com/docs/prod/folders/print/cc2520.html
http://www.semtech.com/images/datasheet/xe1203f.pdf
http://focus.ti.com/docs/prod/folders/print/cc2420.htmll
http://www.semtech.com/wireless-rf/rf-transceivers/sx1212/

Annex V

Projects and Case studies of Sports Related Wearable Monitoring Systems (Part 1/3)

Projects	Pub.	Country	Sport	Platform	Sensors	Location	Storage	Feature Extraction	Processor	Wireless	Software	Power Source	Objective
Wearable System for monitoring running athletes	2003	Greece	Rehabilitation Running	N/S	12 Lead ECG, Respiration transducer (belt on chest), 6 electrogoniometers, 2 temp. probes	Electrog.: joint of lower limbs, Temp. probes: on injury and on contralateral site	N/S "Portal" long-term data logging module	Heart rate, heart rate variability, breath rate, joint angles, temperature of injury and contralateral site, Bayesian inference, neural network fusion, fuzzy logic inference, Dempster-Shafer method, and weighting /voting fusion.	N/S	N/A	N/S	N/S	Optimize treatment and training procedures during rehabilitation, in order to prevent injury relapses and to ensure a prompt return to peak athletic condition
SensVest	2005	European Union	General Usage Data collection	Custom	POLAR heart rate monitor LogIT heart rate receiver Accelerometers	In shirt	N/A	Measuring movement, heart rate, energy expenditure, temperature	ATMEL MCU	N/A	custom-made application	1 PP3 9V battery	Teaching tool for physiological data collection
Skiing analysis system	2005	Switzerland	Skiing	Smart-Its platform.	ADXL210E acc., ADXRS300 gyr., FSR, Infineon KMY10 radar (PU), Sharp GP2D12 infrared	FSR= feet in triangular disposition. 2 accel. Setup trap to tight with Velcro. Gyroscope taped to ski	multimedia card with FAT16	Velocity, ski angle, thight disposition, foot pressure	PIC microcontroller	N/A	SKI analysis software	N/S	Ski performance analysis with video complementation
SensorHogu	2005	USA	Taekwondo	IP	Piezoelectric force sensing	Torso	N/A	Applied force and location	N/S	N/S	IP	two AAA-sized batteries	Force and location sensing system for competition scoring of Taekwondo
WS Network for Body Kinematics Monitoring	2006	Portugal	General Usage	N/S	3-axis acc., 3-axis magnet.	T-shirt	N/S	Temperature, heart rate and frequency rate, additional to motion analysis	N/S	2.4 GHz RF transceiver	N/S	N/S	Monitoring the body kinematics during hidrocinesiotherapy sessions
WS Real-time Games of Martial Arts	2006	Austria	Martial Arts, Video Games	Xsens XBus Master System (XM-B)	8 boxed MT9 sensors (3-axis acc., 3-axis gyr., 2-axis magnetometer, temp. sensor.	Wrists, directly above feet, above knee caps, neck, backbone origin. Master unit on hip	Oqo mobile computer	Motion analysis, frequency range power, discrete fast Fourier transform, frequency entropy	portable computer	N/S Bluetooth	developed a freely available software toolbox		Real-time motion analysis and movement recognition for Wing Tsun (form of martial arts),
Smart Sport Underwear Design	2006	Uni. of Sci. & Tech., China	N/S	N/S	N/S	Underwear	N/S	N/S	N/S embedded on-body processor	Bluetooth and GSM	N/S	N/S	To show the possibility of several biomedical signals acquisition for alert messages and personalized synoptic tables of user's physiological status
Wearable fatigue monitoring system	2006	Toyo University, Japan	Running (as a stress inducing activity)	N/A	2-axis accelerometer (ADXL202E 2005)	Top of head	1 Mbit Flash memory chip	Adopted a time-integral of acceleration trace pattern length, which was defined as the length between the adjacent two acceleration X-Y plots.	8-bit microcontroller	N/A	N/S	8,4 V NiMH battery	Evaluating the degree of tiredness. Artificially introduced physical stress, such as running, made consistent changes in the acceleration trace length. Objective: evaluation of human-computer interaction.

WWSN: Wearable Wireless Sensor Network, WS: Wearable Sensor, Pub.: Publication, N/S= Not Specified, N/A = Not Applicable, PU= Partial used (only used during a stage of the project)

Annex V

Projects and Case studies of Sports Related Wearable Monitoring Systems (Part 2/3)

Project	Pub.	Country	Sport	Platform	Sensors	Sensor Location	Storage	Feature Extraction	Processor	Wireless module	Software	Power Source	Objective
"On-water" wearable lower limb movement analysis in rowing activities	2007	Italy	Rowing	N/S	Custom design sensing leotard with conductive elastomer	lower limbs	remote server	Raw data mapping to lower limb kinematic variables through linear mapping technique and calibration	N/S	I2C Bluetooth	N/S	N/S	Sensing system was developed to monitor kinematic variables of lower limbs of an athlete during rowing activities
Movement Analysis in Rock-Climbers	2007	UCLA, USA	Climbing	10 Crossbow MicaZ	Hitachi Metals H34C[5] 3D	Distributed on limbs	N/S	Subtract 1 from sqr(x2 + y2 + z2) while the climber is moving to get the difference between the applied force vector and unit vector.	Atmel ATmega128L	CC 2420	SOS	N/S	System developed to calculate the energy generated in the limbs of a rock climber in order to establish proficiency level (beginner, intermediate, advance)
MobZombies	2007	USC, USA	Video Games	Sony UX hand-held computer	PNI Vector 2Xe 2D digital magnetic compass, Freescale MMA7260Q 3D acc., InvenSense IDG300, Analog Devices ADXL330 3D acc.	Computer interface	portable computer	Rotation and movement	Portable computer	N/A	MobZombie game	Portable computer	Interface for computer game play
WWSN to Assess Clinical Status	2007	Harvard/MIT USA	N/A	SHIMMER	Freescale MMA7260Q 3-axis MEMS acc., InvenSense IDG-300 2-axis gyr.	Possible waist or hip	MicroSD (max 2Gb)	RMS, approximate, entropy, cross-covariance parameters	TI MSP430	Chipcon CC2420 IEEE 802.15.4 2.4GHz radio	Open-source TinyOS	Rechargeable lithium-polymer battery	Facilitating medication titration in patients with Parkinson's disease and assessing motor recovery in stroke survivors undergoing rehabilitation
Detection of Daily Activities and Sports	2008	Finland	General Usage activity recognition	N/S	Analog Devices ADXL202 acc., Sensorbox: 3D acc., 3D magnet., Environmental temp., illumination, humidity. Skin temp., ECG electrode, Respiratory effort sensor, Oximeter. Garmin eTrexVentureGPS receiver	3D acc.: wrist Sensor box: hip Chest: skin temp., ECG, respiratory effort Hand: oximeter Backpack: GPS, camera and recorder	Flash-card-memory-, 19-channel recorder (EmblaA10, Medcare, Reykjavik, Iceland).	Time-domain features calculated were mean, variance, median, skew, kurtosis, 25% percentile, and 75% percentile. Frequency-domain features included the estimation of power of the frequency peak and signal power in different frequency bands. Speed. Four different classifiers were used: 1) custom decision tree; 2) automatically generated decision tree; 3) artificial neural network (ANN); and 4) hybrid model	N/S	N/A	custom-made application	N/S	Unsupervised activity recognition. Activity recognition with wearable sensors can provide feedback to the user about his/her lifestyle regarding physical activity and sports, and thus, promote a more active lifestyle
Ayushman	2008	Arizona State University, USA	General Usage	MicaZ and TelosB	MicaZ and TeloB internal sensors	N/S	N/S	TeloB: ambient temperature and humidity. MicaZ: blood pressure, blood oxygen and acceleration	Base station on a Dell Axim PDA running Pocket PC 2002	ZigBee	Custom. First IBM J9 JRE based, then .NET (stability issues solved), XML message based	2 AA batteries	Building a real-time patient monitoring system which is secure, robust (available, dependable) and easy to use
ClimBSN	2008	England	Climbing	Nordic nRF24E1 chipset (NLR)	3-axis acc.	Ear-worn	N/S	Principal Component Analysis (PCA). Gaussian Mixture Models (GMM) clustering, Expectation-Maximisation (EM) algorithm	Embedded 8051 compatible microcontroller	Nordic nRF2401 2.4GHz RF transceiver	N/S	N/S	Independent threshold trigger and global angle trigger reference for movement extrapolation

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Annex V

Projects and Case studies of Sports Related Wearable Monitoring Systems (Part 3/3)

Project	Pub.	Country	Sport	Platform	Sensors	Sensor Location	Storage	Feature Extraction	Processor	Wireless module	Software	Power Source	Objective
SEnsing for Sports And Managed Exercise (SESAME)	2008	UK	Sprinting	RS232 interface proprietary board	Xsens MTx 3D inertial sensor	Lower back	remote server	Detailed rapidly moving foot motion	N/S	ConnectBlue OWSPA311g 802.11 module, HIN242ACP RS232 transceiver	N/S	N/S battery pack	N-body wireless inertial sensing system, and analyze our system in three aspects: a) a foot motion analysis using the collected inertial data of sprinters; b) the system's physical characteristics (i.e. weight and operational behavior); and c) the system's wireless performances
Smart-clothing	2008 2009	Portugal	N/S	IRIS Mote model XM2110CA	Flex sensor, which has a variable printed resistor	Belt	N/S	Angle distortion for movement extrapolation	Atmel ATmega1281	2405 MHz to 2480 MHz ISM band, I2C, SPI and UART	open-source TinyOS	2X AA batteries	Fetal Health Monitoring through movement analysis
BIOTEX	2008 2010	European Union, Ireland	General Usage	Mica2dot	Fabric with integrated fluidic channel from Sofileta, absorbent material (Absorbtex) by Smartex, rubber gasket by Thuasne, Red LEDs (Kingbright, L934sRCG) for absorbance detection, skincheck1TM on-skin pH meter, Ion Selective Electrodes for measuring sodium content	waist	N/S	PH and sodium metrics from sweat	Atmel ATmega128L	2.4 GHz IEEE 802.15.4, 250 kbps data rate	N/S	2xAA batteries, External Power 2.7 V - 3.3 V	Development and testing of a fluid handling system for sweat collection and real time pH monitoring, and sodium measurement system discussion
Interactive Snowboarding Assistance System	2009	Switzerland	Snowboarding	Notebook (IBM ThinkPad® T42)	Five 3-axis accelerometers, 8 FSR for pressure sensing insoles	2 Acc: on board; 2 Acc: on each lower leg; 1 Acc on leading hand. FSR 2 on toe-side and 2 on heel-side. Notebook on backpack	N/A	motion analysis, and feet pressure	notebook (IBM ThinkPad® T42)	N/A	N/S	notebook batteries	Performance characterization of common snowboarding maneuvers
Body Sensors for "in-game" biometric data collection	2009	UCLA, USA	General (basketball on trials)	MicaZ	Nonin 3212 XPOD pulse oximeter, MicaZ embedded accelerometer	Oximeter on "off-hand" shoulder, MicaZ on shoe	SensorBase repository	Stress, Importance, Exhaustion and Talent Metrics based on pulse and motion readings, applying Random Finite Set Theory.	Atmel ATmega128L	2.4 GHz IEEE 802.15.4, 250 kbps data rate	N/S	2xAA batteries, External Power 2.7 V - 3.3 V	Stress and exhaustion is quantified and encapsulated within an equation that symbolizes player "readiness" and will include factors such as player talent, and player importance
TennisSense	2009	Ireland	Tennis	TennisSense, based on Ubisense spatial localization system and Foster Miller vest	Foster Miller vest: 3 passive sensors (respiration sensor, thermistor based temp. sensor. Additional acc. is incl. in the HUB	T-shirt	N/S	Physiological information including ambulatory breathing rate and heart rate	N/S	N/S RF	N/S	N/S	Creating a multi-modal sensing platform for providing feedback to tennis coaches and players
Vital-Jacket®	2010	Uni. of Aveiro, Portugal	General Usage	IP	Sports Version: ECG. Cardio Version: 1, 3 or 5 ECG leads and a 3-axis acc. Can be setup to acquire different vital signs (ECG, temp., resp., mov./fall, posture, actigraphy, oxygen saturation, etc.) and psycho-social variables (panic button, medication delivery, activity habits, location, etc.) through wearable or bed-side sensors.	Torso	SD card	general vital signals analysis	IP	Bluetooth	IP software VJ Desktop	Rechargeable battery and recharger	Wearable vital signs monitoring system based on textile integration

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