A Sport Activities Monitoring System based on Acceleration and Rotation Microelectromechanical Sensors

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***Abstract*— Although there are several technological tools to aid sports training, most of them are high cost solutions and generally very specific to a particular sport, which hinders the diffusion of such technologies. This paper presents a low-cost non-invasive microcontroller Sport Activities Monitoring System (SAMS) prototype, which is based on acceleration and rotation microelectromechanical sensors (MEMs) for obtaining biomechanical data during the athlete's training, without leaving the natural environment of his activities. The sensors signals are wirelessly transmitted from the SAMS to the computer in order to process the data, through an easy and intuitive Virtual Instrument (VI) interface developed in LabVIEW®. This VI saves and displays real-time data in a graphic form. The experimental results were obtained in two different environments: first we used a stationary bike and then we tested the SAMS in a professional cycle track. The system allows the acceleration acquisition in the range form $\pm$1,5 G until $\pm$10 G and rotation in the span of $\pm$50 °/s. The maximum transmission range is about 70 m. The SAMS has a small size (37x49x20 mm) and lightweight (40 g), making it a versatile monitoring system to aid athletes and coaches during the training, allowing refinements on the technique. The SAMS is also a suitable tool for the physical education research area.**

Keywords: accelerometer, gyroscope, sport monitoring, virtual instrumentation, wireless communication, real time feedback.

I. INTRODUCTION

Currently advances on microelectronics and MEMs sensors, are each time smaller, with low power consumption and affordable prices making it more feasible and permitting its application on sports. Accelerometers, gyroscopes, microphones and cameras among others, lend themselves suitable to a wide range of sports applications [1], making possible to obtain biomechanical, physical or cognitive information from monitoring the athletes performance during their trainings or sport practices. New wireless communication standards like Bluetooth® and Zigbee^{TM}, provide a platform for networking sensors, that can be widely applied in the healthcare and in sports [2] since it allows data transmission without mobility interfering. The athlete's performance depends on the environment where he or she is being monitored [2], for example: laboratory, inside/outside training, competition or playing field conditions. In addition to that, it is known that when feedback is provided in an appropriate manner, motor skill acquisition improves significantly. Consequently, feedback is a major factor in the improvements of sport skill performance [3]. Furthermore, systems with immediate feedback increase the athlete's motivation.

II. HARDWARE SYSTEM PROTOTYPE

Figure 1 shows the block diagram of the Sport Activities Monitoring System (SAMS) prototype, which is divided in two boards: the first one, has the acceleration and rotation sensors, a microcontroller, a radiofrequency module and a battery. This is the mobile part of the prototype and can be attached to the athlete's body. The second board, also called base station board, was adapted from a USB-RogerCom® board [4], and incorporates a radiofrequency module. This station board is directly connected to the computer's USB port, in order to acquire the sensors' data.

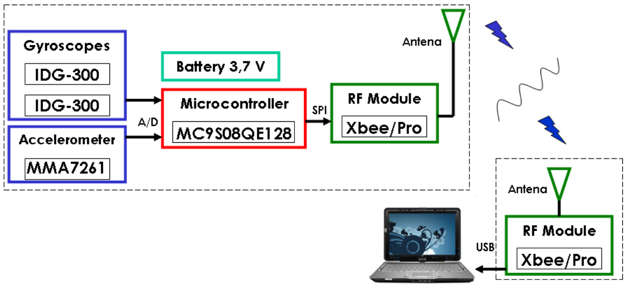


Fig. 1. Block diagram of the system prototype.

The prototype sensors were chosen by taking into account their operation range, size, energy consumption, number of axes, type of output, encapsulation and price, keeping this in mind, the accelerometers MMA7260 and MMA7261 from Freescale^{TM} and the gyroscopes IDG-300 and IDG-1004 from InvenSense^{TM} were chosen. With regards to the microcontroller, we selected a low power, eight bit MC9S08QE128 from Freescale^{TM}. The radiofrequency module Xbee/XbeePro from Digi^{TM}, and a rechargeable 3,7 V lithium prismatic battery were also selected.

Accelerometers: The MMA7260 (introduced in 2005 by Freescale^{TM} [5]) and the MMA7261 [6] are MEM's tri-axis acceleration sensors with selectable sensitivity (1,5/2/4/6 G), low current consumption (500 μA), sleep mode (3 μA), low voltage operation (2,2 to 3,6 V) and low cost (3,35 USD). The output voltage is ratiometric and proportional to the acceleration, this simply means that the output offset voltage and sensitivity will scale linearly with applied supply voltage.

Table I presents the typical sensitivity for 3,3 V power supply voltage and Figure 2 shows the sensor dynamic acceleration axis.

TABLE I
MMA7260QT AND MMA7261QT SENSITIVITY.

		MMA7260QT		MMA7261QT	
G2	G1	Range [G]	Sen. [mV/G]	Range [G]	Sen. [mV/G]
0	0	1,5	800	2,5	480
0	1	2	600	3,3	360
1	0	4	300	6,7	180
1	1	6	200	10	120

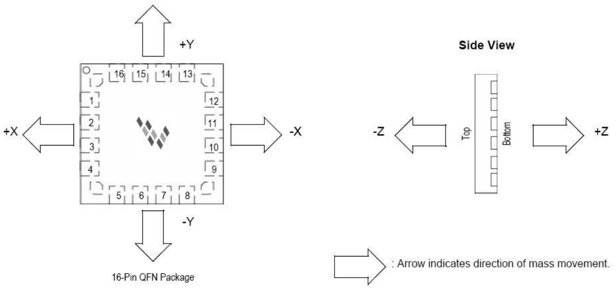
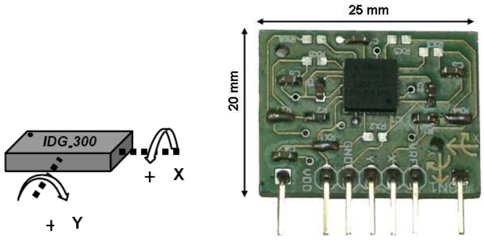


Fig. 2. MMA7260QT and MMA7261QT dynamic acceleration axis [5].

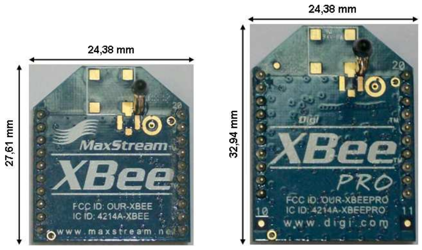
Gyroscopes: The IDG-300 and IDG-1004 are an integrated dual-axis angular rate sensors (gyroscopes). Both of them use InvenSense^{TM}'s proprietary and patented MEMS technology with vertically driven, vibrating masses to make a functionally complete, dual-axis angular rate sensor [7]. The output voltage of the gyroscope is proportional to the angular velocity. The IDG-300 full scale range is ±500°/s, sensitivity 2 mV/°/s, low voltage operation (3,0 to 3,3 V) and low cost (30 USD). For IDG-1004 [8] the main difference is the full scale range ±50°/s, and the sensitivity 4 mV/°/s. Figure 3 presents the rotation axis and the gyroscope board witch is going to be part of the SAMS, allowing to obtain the yaw rotation.



(a) Rotation axis [7] (b) Gyroscope Board

Fig. 3. IDG-300 and IDG-1004 rotation axis and gyroscope board.

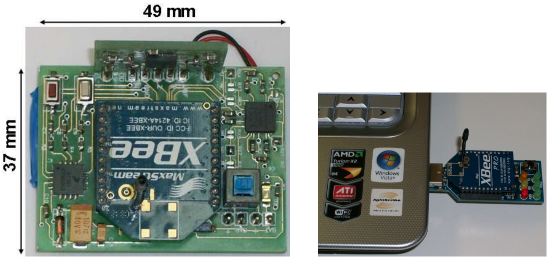
Xbee/XbeePro Modules: Wireless communication between the mobile board and the base station board was achieved with the Xbee/XbeePro RF modules from Digi. This modules were introduced in the market in 2007, and were designed to meet the IEEE 802.15.4 standard (ZigBee^{TM}). The modules operate within the ISM (Industrial, Scientific and Medical) 2.4 GHz frequency band, sending and receiving signals and physically pin-to-pin compatible with each other [9]. Figure 4 presents the Xbee/XbeePro modules.



(a) Xbee (b) Xbee-Pro

Fig. 4. Xbee e Xbee-Pro modules from Digi.

Figure 5 shows the SAMS mobile and base station boards. To increase the possible test scenarios, two different versions of the SAMS were constructed and their characteristics are presented in Table II.



(a) Mobile board (b) Base station board

Fig. 5. SAMS mobile and the base station boards.

TABLE II
SAMS MOBILE BOARD SPECIFICATIONS.

Characteristics	I Prototype	II Prototype
Dimension	37x49x20 mm	
SAMS Final Weigh	40,14 g	40,08 g
Acceleration	MMA7260	MMA7261
Gyroscope	IDG-1004	IDG-300
RF Transmission Range	70 m	
MCU	HCS08QE128	HCS08QE64
Sampling	30 Hz	
Flash Memory	128 kB	64 kB
RAM Memory	8 kB	4 kB
Battery	700mAh/3,7 V	
Duration	10 h	
SAMS PCB Weight	11,70 g	11,64 g
Gyroscope PCB Weight	2,40 g	
Battery Weight	9,38 g	
Plastic Box Weight	15,47 g	

III. SOFTWARE SYSTEM PROTOTYPE

The software of the Sport Activities Monitoring System (SAMS) prototype, was divided in two parts. The first one, is a firmware programmed in C into the microcontroller, this firmware controls all the process in the mobile board, including: data acquisition, optional processing, power consumption, and data transmission. The second part of the software, is a Virtual Instrument (VI) interface developed on LabVIEW®, which is a graphical programming language that has been widely adopted throughout industry, academia, and research labs as the standard for data acquisition and instrument control software [10]. This VI allows the selection of the sensors which are going to be use, select the acceleration range, enable preprocessing, along calibration, data processing, saving and displaying real time data in a graphic form over an intuitive user interface. The SAMS' frontal panel is presented in Figure 6.

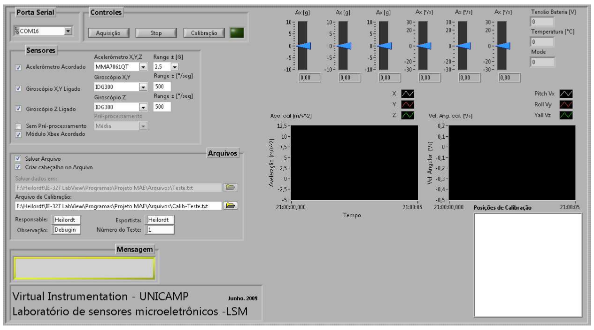

Porta Serial: COM16
Sensores
☑ Acelerômetro Acordado — Acelerômetro X,Y,Z: MMA7061QT — Range ± [G]: 2.5
☑ Giroscópio X,Y Ligado — Giroscópio X,Y: IDG300 — Range ± [°/seg]: 500
☑ Giroscópio Z Ligado — Giroscópio Z: IDG300 — Range ± [°/seg]: 500
☐ Sem Pré-processamento — Pré-processamento: Média
☑ Módulo Xbee Acordado
Arquivos
☑ Salvar Arquivo
☑ Criar cabeçalho no Arquivo
Salvar dados em: F:\Heilordt\IE-327 LabView\Programas\Projeto MAE\Arquivos\Teste.txt
Arquivo de Calibração: F:\Heilordt\IE-327 LabView\Programas\Projeto MAE\Arquivos\Calib-Teste.txt
Responsable: Heilordt
Esportista: Heilordt
Observação: Debugin
Número do Teste: 1
Tensão Bateria [V]: 0
Temperatura [°C]: 0
Mode: 0
Virtual Instrumentation - UNICAMP
Laboratório de sensores microeletrônicos -LSM
Junho. 2009

Fig. 6. SAMS virtual instrument frontal panel.

SAMS calibration: In order to eliminate the offset from the sensors, a calibration process was developed. This process measured the gravity acceleration by each one of the accelerometer axes in three different positions by aligning the normal vector of the sensor, with the gravity vector in every position and keeping the other axis without acceleration. For the calibration task, the program guides the user to align the sensor's box in each one of the positions as shown in Figure 7. Finally, after the calculations, the offset value for every axis is saved in a file and read by the SAMS' VI during the startup.

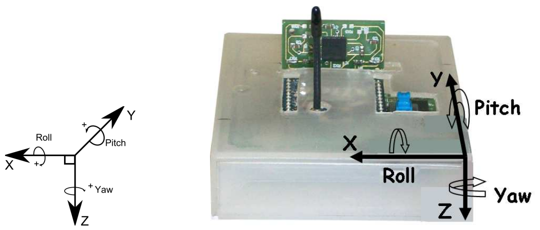

(a) Position 1 (b) Position 2 (c) Position 3

Fig. 7. SAMS mobile board calibration positions.

SAMS fixation and orientations: The SAMS was encapsulated and adapted with a fixation system to let it be easy fasten to the athlete. The axis and rotation coordinates are presented in Figure 8.

IV. EXPERIMENTAL RESULTS

The experimental results were obtained in two different environments: first we use a stationary bike and then we tested the SAMS on a professional cycle track. In these bike test, the sensor was fixed in the right ankle of the athlete as shown in Figure 9.



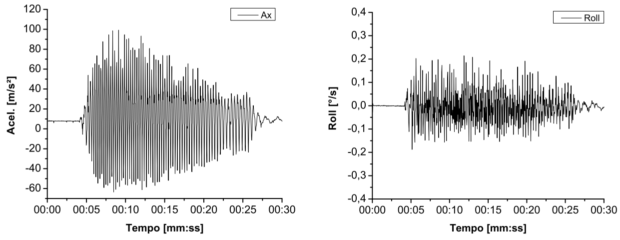
(a) (b)

Fig. 8. SAMS mobile board axis and rotation coordinates.

(a) (b)

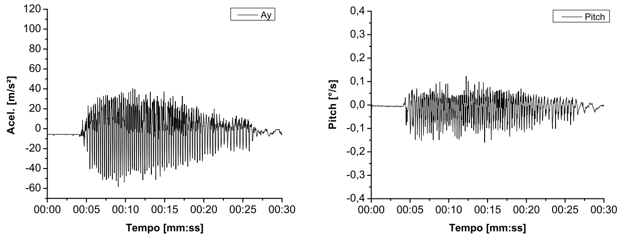
Fig. 9. Fixation in the right ankle during the testes.

Stationary bike test: One of the tests with the stationary bike, was the Wingate test [11]. This is a test used to evaluate the maximum power and anaerobic capacity. The Wingate is a 30 seconds test, during it, the athlete tries to pedal as many times against a fixed resistance, aiming to generate as much power as possible in that period of time. The power generated during the 30 seconds is called the average power and a power peak usually occurs within the first 5 seconds of the test. Figure 10, 11, 12 and 13, shows the acceleration and angular velocity for each axis and the temperature, respectively.



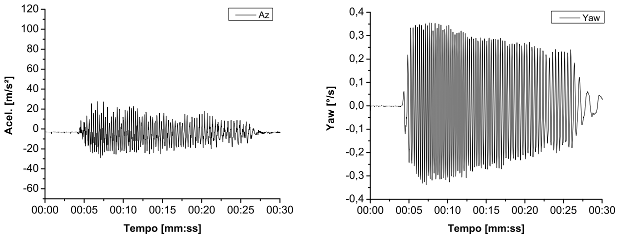
(a) A_x (b) *Roll* (V_x)

Fig. 10. Acceleration A_x and angular velocity Roll (V_x).



(a) A_y (b) *Pitch* (V_y)

Fig. 11. Acceleration A_y and angular velocity Pitch (V_y).



(a) A_z (b) *Yaw* (V_z)

Fig. 12. Acceleration A_z and angular velocity Yaw (V_z).

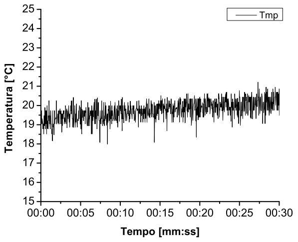
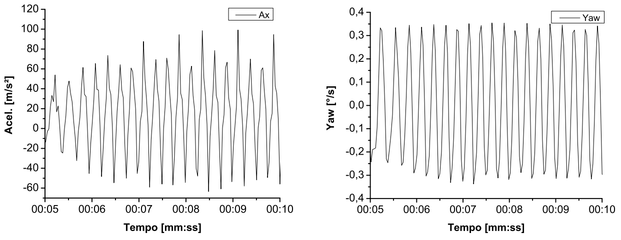


Fig. 13. SAMS temperature.

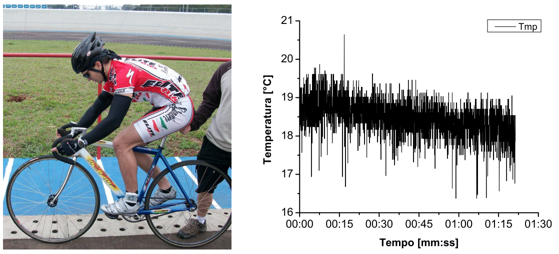
In the field tests we used the SAMS II prototype, with an acceleration range of ±10 G and rotation span of ±50 °/s. Figure 14 presents the acceleration A_x and rotation Yaw (V_z) during the firsts five seconds of the Wingate test. In this time window, a clear view of the signals format is presented with a maximum acceleration peak of 98 m/s^2 in the X axis and a symmetrical alike sine signal in the yaw component.



(a) A_x (b) *Roll* (V_x)

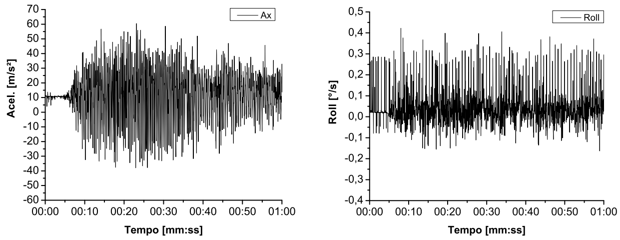
Fig. 14. Acceleration A_x and angular velocity Yaw (V_z) detail.

Cycle track test: In the cycle track test the SAMS was tested in a real sport scenario, with a maximum wireless transmission range about 70 m. One of the tests in the cycle track was an static start shown in Figure 15(a). Figures 16, 17 and 18, show the acceleration and angular velocity for each axis, respectively. The temperature acquired by the SAMS is shown in Figure 15(b).



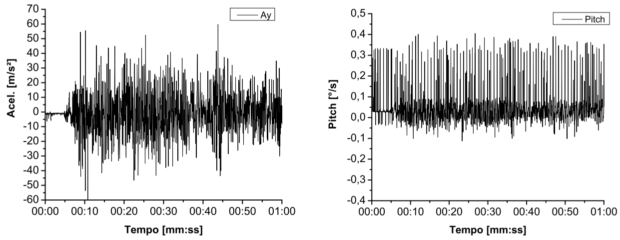
(a) (b)

Fig. 15. SAMS fixation in the ankle and temperature.



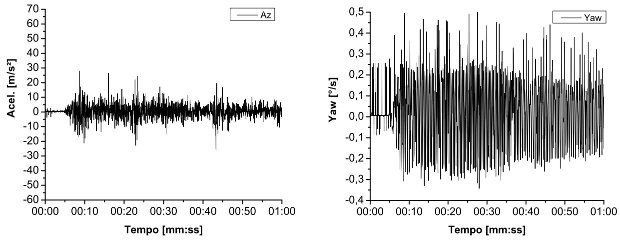
(a) A_x (b) *Roll* (V_x)

Fig. 16. Acceleration A_x and angular velocity Roll (V_x).



(a) A_y (b) *Pitch* (V_y)

Fig. 17. Acceleration A_y and angular velocity Pitch (V_y).



(a) A_z (b) *Yaw* (V_z)

Fig. 18. Acceleration A_z and angular velocity Yaw (V_z).

V. CONCLUSIONS AND FUTURE WORKS

A. Conclusions

- The calibration process made with SAMS was successfully implemented, making it possible to compare the measured accelerations in magnitude with a minimum margin of error.
- The SAMS has small size (37x49x20 mm) and lightweight (40 g) which facilitates its use in sports.
- The SAMS permits monitoring sports activities in a real sport scenarios, as it is portable, versatile, and a low-cost system.
- The incorporation of the SAMS wireless communication, added mobility without limiting the natural movement of the athlete, with a maximum wireless range of 70 m.
- Data displayed in real time in the graphical virtual instrument interface, allows an instantaneous feedback to athletes and coaches during training.
- From the tests conducted in partnership with the Biome-

chanics Instruments Laboratory (LIB) at UNICAMP, it became clear that the SAMS prototype is a versatile alternative to aid athletes and coaches during the training, allowing techniques refinement. The SAMS is also a suitable tool for physical education research area.

- Before implementing any type of filtering, obtained “raw”data must be analyze together with the Biomechanics Instruments Laboratory (LIB).

B. *Future works*

In the next stage we pretend to set up a network with multiple SAMS systems, making it possible to fix the SAMS in more than one body segment and perform simultaneous data acquisition. The system will also be tested in others sports, and some filtering, data processing will be added.

VI. ACKNOWLEDGEMENTS

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