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WSN and M2M for Mountain Biking Performance Assessment

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Thesis to obtain the Master of Science Degree in

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Abstract

The thesis describes the design and implementation of the "Smart Mountain Bike" monitoring system enables the acquisition, storage and visualization of data on athlete training referring the cycling activity. The signals provided by the measurement channels are acquired and processed in order to better understand of the variables involved in this sport and consecutively to improve the methodology for the training of athletes.

The "Smart Mountain Bike" system consists of a wireless sensor network that acquire data related to the applied force and body position during a training session. Each network end node comprises a microcontroller, a conditioning circuit and a set of sensors. The coordinator node Zig Bee compatible is composed by microcomputer (eg. Raspberry PI or BeagleBone), a GPS and an IMU. The cloud interfacing is done using a 3G/UMTS USB module connected to the microcomputer board. As the main component of the cloud the implemented database is accessed through a mobile application implemented in an Android OS device. The mobile application allows the visualization of the acquired and processed data by the user expressed by the athlete or the coach.

This system can be used for other sports and other activities in which it is necessary to monitor physical activities such as physical therapy.

Keywords: wireless sensor network; machine-to-machine; bicycle; cloud; mobile application

Resumo

Este documento descreve o desenvolvimento de um protótipo "Smart Mountain Bike", este sistema de monitorização permite a recolha, armazenamento e visualização dos dados relativos aos treinos do atleta durante a atividade ciclismo. Esta informação contribui para um melhor entendimento das variáveis envolvidas da prática deste desporto e consecutivamente, melhorar a metodologia de treino dos atletas.

O sistema "Smart Mountain Bike" é constituído por uma rede sensores sem fios que recolhe a dados sobre força aplicada e posição do corpo numa sessão de treino, cada nó final da rede é composto por um microcontrolador, um circuito condicionador e um conjunto de sensores. O nó coordenador é composto por um microcomputador, um recetor GPS, um IMU e um módulo de comunicação móvel, este módulo permite um cenário *Machine-to-Machine*, onde o microcomputador comunica com o a nuvem permitindo o armazenamento da informação recolhida numa base de dados. Esta informação é acedida através de uma aplicação móvel desenvolvida para este projeto, a aplicação móvel permite ao utilizador, atleta ou treinador, visualizar e correlacionar os dados.

Este sistema pode ser utilizado noutros desportos e noutras atividades em que seja necessário monitorizar atividades físicas, como por exemplo, fisioterapia.

Palavras-chave: rede de sensores sem fios; bicicleta; nuvem; aplicações móveis

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List of Acronyms

AHRS	Attitude and Heading Reference System
API	Application Programming Interface
DB	Data Base
DOF	Degree Of Freedom
EDGE	Enhanced Data Rates for GSM Evolution
FSR	Force Sensitive Resistor
GPRS	General Packet Radio Service
GPS	Global Positioning System
GSM	Global System for Mobile Communications
HSDPA	High-Speed Downlink Packet Access
HTTP	HyperText Transfer Protocol
IaaS	Infrastructure as a Service
I²C	Inter-Integrated Circuit
IEEE	Institute of Electrical and Electronics Engineers
IMU	Inertial Measurement Unit
IoT	Internet of Things
LAMP	Linux, Apache, MySQL and PHP
LIVM	Low Impedance Voltage Mode
M2M	Machine-to-Machine
NIST	National Institute of Standards and Technology
PaaS	Platform as a Service
PHP	Hypertext Preprocessor
REF	THref - Temperature-Humidity Reference
SaaS	Software as a Service

SCL	Serial Clock Line
SDA	Serial Data Line
SQL	Structured Query Language
TTFF	Time-to-First Fix
UMTS	Universal Mobile Telecommunications System
USB	Universal Serial Bus
WSN	Wireless Sensor Network

1. Introduction

1.1. Motivation and Objectives

Mountain bikes are typically ridden on single track trails and other unpaved environments. These types of terrain commonly include rocks, loose gravel, roots, and steep grades (both inclines and declines) which demands a continuously adaptation from the rider aiming to achieve a tiny balance between speed and safety. Mountain bikes are built to handle this terrain and the obstacles that are found in it like logs, vertical drop offs, and smaller boulders. Along the trail the rider controls the bike through the hands, feet and body positioning. Thus going down a track in mountain bike demands a close interaction between rider and bicycle which is highly constrained by external factors such as the track slope and obstacles. It is that interactive behavior between bicycle and rider that we aim to capture.

The system prototype "Smart Mountain Bike" has the purpose to collect data from several sensors (the IMU and force sensors) as part of wireless sensor network nodes and to analyze the cyclist behavior and performance consider as set of metrics such as i) braking intensity; ii) braking frequency; iii) pedal strength; iv) rider body positioning; v) bicycle oscillations on the three plans of motion. Based on appropriate analysis the rider – bicycle interactions are extracted. This data after a primary processing on the bicycle side that is working as client, is stored on a “server” side, making use of a machine-to-machine (M2M) communication based on 3G/UMTS modem connected to the embedded computer installed on the bicycle that is also is working as the coordinator node of the WSN. The server materialize the Cloud

Recent technological evolution of mobile devices, allows people to access mobile applications related to sports like running, cycling or gym workout. Considering the state of art in this field an innovative mobile application that allow recreational practitioners, as well as athletes and their respective coaches to obtain new performance data and consecutively adapt the training methods and improve sports performance was carried out. Assisted training may conduct to better performance of any athlete, whether professional or recreational.

1.2. Dissertation Overview

This dissertation presents the prototype developed for the mountain bike monitoring system. Each chapter represents a topic of this work and its outcomes. It is composed by 7 chapters that are following presented:

Chapter 1, which gives a brief insight about the work, its motivations and objectives.

Chapter 2 gives an overview of the related work described in the literature.

After a brief overview of the system, Chapter 3 focuses on Smart Mountain Bike architecture.

Chapter 4 gives further insight into communication and data storage on cloud.

Chapter 5 describes the entire structure of the mobile application, including its features and design.

Chapter 6 presents and discusses the results and evaluates the platform usability and performance.

Finally, Chapter 7, concludes this dissertation, by showing its achievements and providing suggestions for future improvements.

2. Related Work

Primarily is made a practical approach concerning the optimal choice of the sensors to collect the data was carried out. The second topic refers the design and implementation of WSN monitoring systems and most used WSN protocols. Then is given focus to cloud computing and the Internet of Things solutions that enable new machine-to-machine communications. An important part of the study is related to the mobile applications development topics including the evolution of the applications market and the selection of an operating system. Finally a brief presentation of other cycling monitoring hardware

2.1. Sensors

The sensors are different depending on the variable they are measuring. In this project the aim is to collect information on the force applied to the brakes and the bike pedals, collect information on the position and acceleration of the athlete and the bike, and also collect GPS information for geo-referencing. Therefore, we use force sensors to measure the forces applied, IMU collect information on bycicle-rider interaction, and GPS receiver to allow tracking of training.

Force sensors are necessary in multiple applications such as robotics [1] and biomechanics, for example in the analysis of force distribution in movements like grabbing [2] or walking. In this context different force sensors are applied:

- Strain gauge sensors consist of a pattern of strain gauges mounted on a deformable structure. The force applied on the sensor induces strains in the structure which are evaluated by strain gauges [3].
- Piezoelectric force sensors, such as the LIVM force sensor (Dytran Instruments Inc. CA, US), contain thin piezoelectric crystals generating analog voltage signals in response to applied dynamic forces.
- Thin film piezoresistive force sensors such as the FSR (Interlink Electronics, Camarillo, CA, US) and the FlexiForce® (Tekscan Inc., Boston, MA, US) sensors have their resistance varying with the applied force. They exhibit a lower accuracy than the other types, but their very small thickness allows a placement directly in contact with a human, for example for tactile sensing [2].

With this in mind and taking into account that in this project, the sensors are applied in bicycle gloves to measure force applied the brakes and in the shoes to measure the force applied to the pedals, the sensors used are type Thin film piezoresistive force sensors due to flexibility, thinness and availability in the market. We opted for the A201 model Flexi-force (Tekscan Inc., Boston, MA, US).

Inertial Measurement Unit (IMU) sensors are used extensively in many different movable applications. Recently, the improvements and applications of IMU have increased through various areas such as manufacturing, navigation, and robotics. IMU are mainly used in devices to measure velocity, orientation, and gravitational force. The accelerometer is used to measure the inertial acceleration. While gyroscope measures angular rotation. Both sensors typically have three degree of freedom to measure from three axes. Later, IMU technology has advanced with another sensor type – magnetometer. Magnetometer measures the bearing magnetic direction, thus it can improve the reading of gyroscope.

Taking into account the dynamic interactions involved in bicycle-athlete opted for IMU with three types of sensors: accelerometer, gyroscope and magnetometer, this type of sensor is good for orientation dynamic calculation in the short and long run less drift when errors occur. Another advantage of using three sensors is to increase the degree of freedom (DOF) of 6-DOF (accelerometer and gyroscope only) to 9-DOF, the number of DOF represents the measurement in x, y, and z axis for each sensor. Usually, the higher the number of DOF, the more accurate sampling of the data.[4].

The Global Positioning System (GPS) is a space-based satellite navigation system that provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites [5] [6]. Many civilian applications use one or more of GPS's three basic components: absolute location, relative movement, and time transfer.

- Cellular telephony: clock synchronization [6] enables time transfer, which is critical for synchronizing its spreading codes with other base stations to facilitate inter-cell handoff and support hybrid GPS/cellular position detection for mobile emergency calls and other applications.
- Fleet Tracking: the use of GPS technology to identify, locate and maintain contact reports with one or more fleet vehicles in real-time.

- Recreation: for example, geocaching.

Tracking the route of training is essential not only by the location of the athlete, but also because it allows collecting altimetry and speed. These data together with the values collected by the sensors can better understanding of the performance of the athlete.

2.2. Wireless Sensor Networks

Regarding the sensor network, a wireless sensor network was considered taking into account that allows extended motion freedom and also permit to deploy the WSN nodes in different locations. In recent years the WSN are used in various monitoring applications, such as:

- Monitoring indoor and outdoor environment to measure temperature and humidity values (REF) and meteorological conditions in different areas [7].
- Monitoring health - collect information from biosensors [8].
- Monitoring of human movement - gathering information from a physical activity such as by heart rate measurement [9].

The creation of standard protocols is essential to the operation of these networks. The IEEE standard 802.15.4 and ZigBee protocol has as objectives to provide a stable and secure communication, the low energy consumption, an easy installation, reduced maintenance effort and low cost. The ZigBee protocol was developed by the ZigBee Alliance, an organization composed by several companies (including, for example, Logitech, Intel, LG, Cisco, Sony, Samsung [10]).

In recent years, advances in wireless sensor networks (WSN) have enabled the use of these networks for monitoring applications such as the examples mentioned above, and there are some low-cost structures already documented using the Zig Bee protocol. Two low-cost structures are provided below:

- The framework designed for monitoring applications, based on Wireless Sensor Networks documented in article [11] gives us an low cost framework. In terms of hardware, makes use of XBee modules and uses an Arduino compatible board with this hardware allows to significantly reduce the cost in the project.

- The prototyping system for Sensor Networks documented in article [12] gives us another low cost framework. In particular, using the Arduino low-cost microprocessor platform and the XBee low-cost Zigbee networking modules.

In this project we opted for the development using Arduino open source hardware with XBee modules and configured to operate within the ZigBee mesh network standard.

2.3. M2M, IoT and Cloud Computing

Machine-to-machine (M2M) communications in the context of the mobile Internet has been a subject of intense discussions over the past years. Some technological motivations such as the proliferation of mobile internet in terms of coverage and mobility support, and the semiconductor industry's shrinking lithography and improved yield continue to reduce chipset cost and power consumption, are primary factors for the propagation of M2M communications [13].

Due to mass use of the Internet and the ability to connect new devices to the network, this leads us to the evolution of the Internet of Things (IoT) and the creation of new opportunities and challenges [14]. Some opportunities come with this new paradigm, are examples, smart home, assisted living or vehicle safety, however there are challenges such as increased traffic, the huge amount of data and real-time requirements for data processing.

In this scenario, Cloud Computing [15] is a new paradigm that provides computing power, storage and software services and a scalable virtualized manner. The US National Institute of Standards and Technology (NIST) has published a working definition [16] that seems to have captured the commonly agreed aspects of Cloud Computing. This definition describes Cloud Computing using:

- Five characteristics: on-demand self-service, broad network access, resource pooling, rapid elasticity, and measured service.
- Four deployment models: private Clouds, community Clouds, public Clouds, and hybrid Clouds.
- Three service models: Software as a Service (SaaS), Platform as a Service (PaaS), and Infrastructure as a Service (IaaS).

Sensor-Cloud [17] is a new paradigm for cloud computing that uses the physical sensors to accumulate its data and transmit all sensor data into a cloud computing infrastructure. Sensor-Cloud handles sensor data efficiently, which is used for many monitoring applications. This architecture allows to store and process the sensor data in accessible form, available timely, and cost-effective [17] [8]. It also allows easier integration with new mobile devices like tablets or smartphones through customized mobile applications access and display all sensor data.

2.4. Mobile applications

Mobile devices (tablets/smartphones) benefited from a great development of technology over the years and are replacing the personal computer. Google's Android is the most popular operating system available on the market [18]. Its popularity is due to it being an open code operating system, so have cheaper costs for businesses, and companies can customize the Android interface as they see fit, leading to various graphical interfaces on the same version of Android.

Currently thousands of mobile applications are placed on the market every day [19], some of these apps are related to the use of bicycles and cycling but, most of these only collect information via mobile phone modules (GPS, accelerometer and gyroscope) and in some cases also through a Bluetooth external heartbeat sensor [20]. The best applications according to bike radar [21] are:

- Strava - While you can use Strava [22] for speed and distance, most riders use the app with their phone in their jersey pocket to record their route, and times on Strava segments, while out on the ride. Once done, uploading a ride results in automatic ranking of your times over popular stretches of road and trail.
- CycleMeter – Cyclemeter [23] turns your iPhone into a great cycling computer – if you're down for putting your iPhone on your handlebars. It is similar to Wahoo Fitness in its wealth of customizable options during the ride, but you also get as smorgasboard of post-ride analysis.
- MapMyRide - MapMyRide [24] is similar to CycleMeter, but it benefits from the parent company's online history with route mapping software. The app is better equipped for tracking – not only rides but your nutrition, weight and more – but it can also get you where you need to go. The app works with any Bluetooth

Smart sensor (and ANT+ sensors with a plug-in), and it offers a competitive option for popular routes.

- Google Maps - The latest Google Maps app, although still in beta for cycling, is the world's best navigation tool for your phone. Just like you use your phone on the fly to find places, read a few reviews, and then go to the one you select, you can use Google Maps to do so – but get there on bike paths and bike-friendly routes.

2.5. Other Cycling Monitoring Hardware

Cycling is a complex physical activity that involves a broad set of movements. This movement can be studied using instrumented bikes [25]. The placement of sensors on the bike parts and equipment allows us to collect other information such as the applied force and accelerations. This type of study allows the creation of models that describe the movement and balance. The research in this field are especially related to analysis of synchronous braking on a bicycle that are reported in [26].

3. Smart Mountain Bike: System Prototype Description

The prototype developed for the collection, storage and visualization of data is composed of three main blocks:

- **Smart Bike** - data acquisition and routing;
- **Cloud** - data storage and management;
- **Mobile Application** - data process and visualization.

The overall monitoring system is represented by the Figure 3-1.

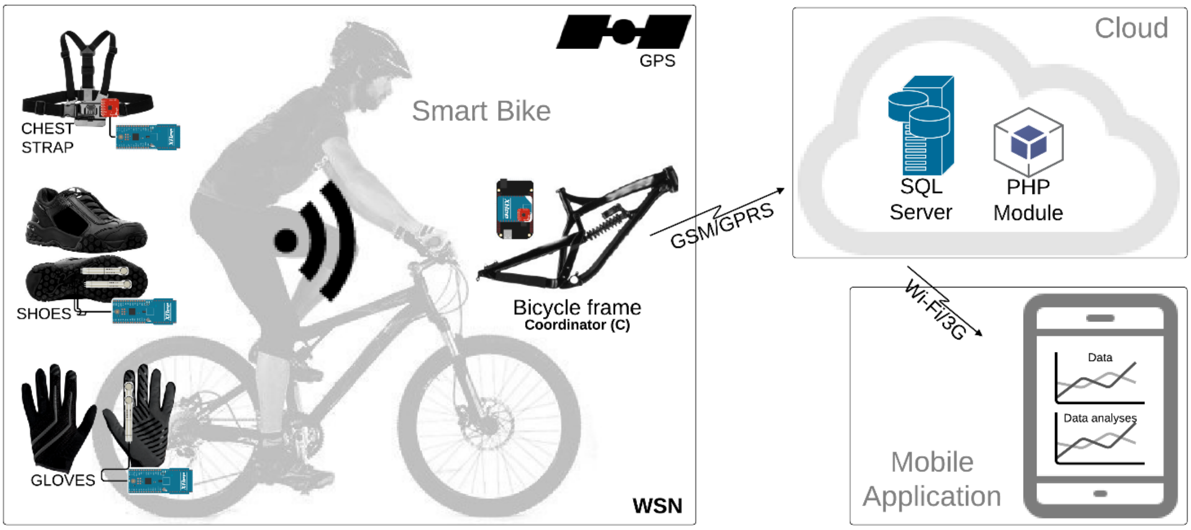


Figure 3-1 Smart Mountain Bike Architecture

The “Smart Mountain Bike” system consists of three blocks. The first, called Smart Bike consists of a wireless sensors network where sensors are placed on sports equipment such as gloves, shoes, chest strap and bicycle frame. Each of the end nodes have a ATmega328P microcontroller to make the acquisition and processing of primary data, this is then sent to the network core that consists of an embedded computer that handles the communication with the server that materialize the cloud. The second block consists of a server with a SQL database to ensure the storage of all information collected and to perform the advanced signal processing of the data. Finally, the mobile application that access data stored on the server, the app is developed for Android OS and it analyzes and correlates all user information. The data visualization is made through a friendly graphical user interface.

This chapter is based on the block "Smart Mountain Bike", briefly, consists of a WSN where each node collects data from the sensor node and performs primary processing and finally sends it to the coordinator node. The coordinator node has sensing of the type IMU and GPS receiver, and in addition to receiving data from other nodes sensing also handles communication with the server.

In the following topic they are highlighted all sensing components used.

3.1. Sensing Components

The end nodes placed in gloves to measure force applied on brakes and on shoes to measure pressure applied on pedals are composed by sensors of the type force sensors. The IMU is used in chest strap coupled to rider and in coordinator node placed in bicycle frame in order to measure the rider-bicycle interactions. The coordinator node is composed by two sensing nodes, they are the IMU and GPS receiver.

3.1.1. Force Sensors

Force sensors are applied on the fingers of the gloves and on the soles of shoes to measure the applied pressure on the brakes and pedals respectively. The force sensor is materialized by A201 FlexiForce® thin film piezoresistor (Figure 3-2) included in a voltage divider implementation.

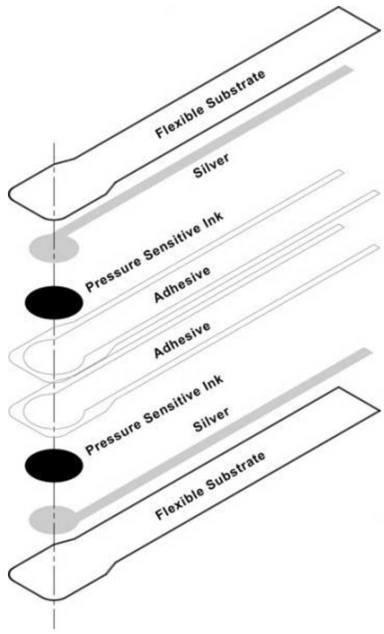


Figure 3-2 FlexiForce® a201 Construction

The FlexiForce force sensor is an ultra-thin, flexible printed circuit. The standard A201 force sensor is constructed of two layers of substrate (polyester) film. On each layer, a conductive material (silver) is applied, followed by a layer of pressure-sensitive ink. Adhesive is then used to laminate the two layers of substrate together to form the force sensor. The active sensing area is defined by the silver circle on top of the pressure-sensitive ink. Silver extends from the sensing area to the connectors at the other end of the sensor, forming the conductive leads. A201 sensors are terminated with male square pins, allowing them to be easily incorporated into a circuit. In addition to appropriate physical characteristics for this application, as the sensors have typical values of Performance: an error of less than 5%, duration of response less than 5 microseconds, and a force that varies from 0 to 440N linearity.

When the force sensor is unloaded, its resistance is very high the output of conditioning circuit being zero while when a force is applied to the sensor, the sensor resistance decrease [27]. In the figure below, the plot shows both the Force vs. resistance and Force vs. conductance (1/R).

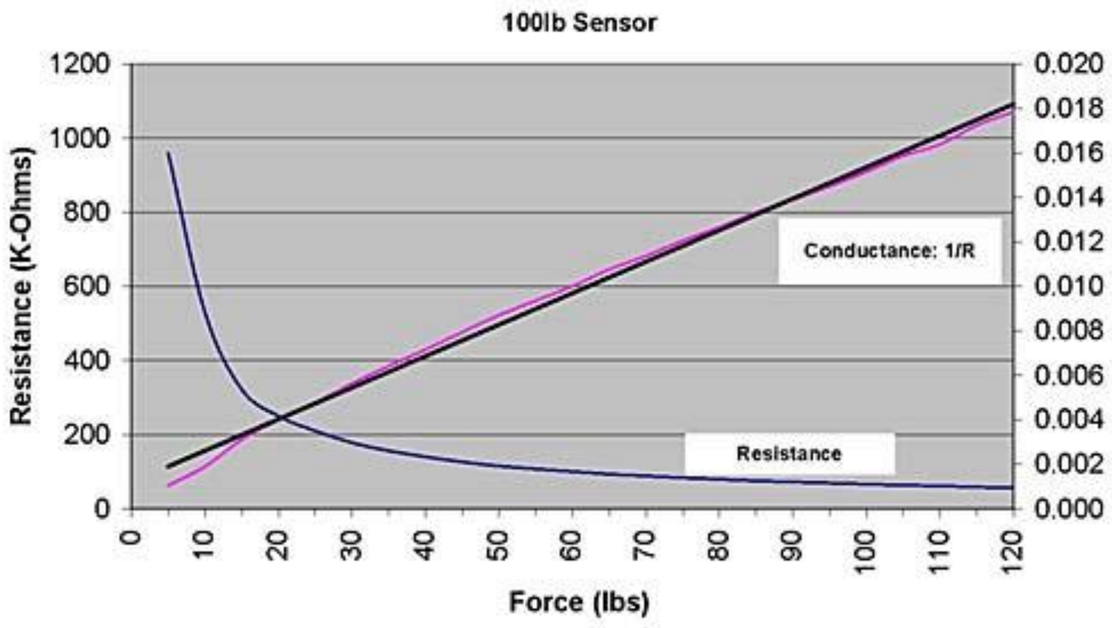


Figure 3-3 Force vs. resistance and Force vs. conductance

One conditioning circuit is needed because the acquisition module only reads voltage values. The conditioning circuit voltage used is presented on Figure 3-4.

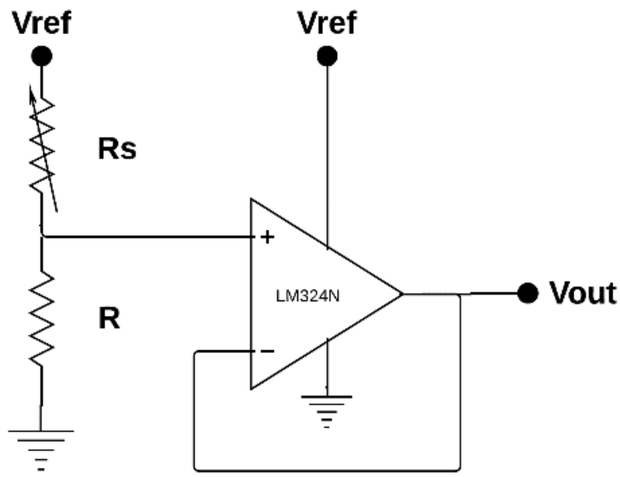


Figure 3-4 Conditioning circuit for force sensors

The conditioning circuit output voltage is given by:

$$Vout = \frac{R}{Rs+R} \times Vref \quad \text{(eq.1)}$$

Where, the parameters in equation (eq.1) are defined as follows:

- **Vref**: is the reference voltage [V];
- **Rs**: is the variable resistance, force sensor [Ω];
- **R**: is the reference resistor [Ω];
- **Vout**: is the output voltage [V];

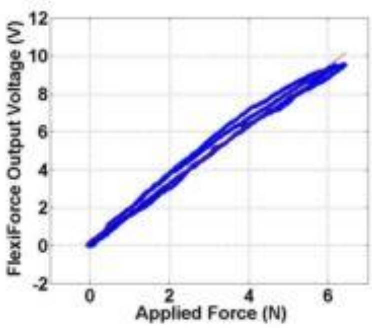


Figure 3-5 Example of calibration of the Flexiforce [28]

A linear model was identified from the calibration curve (Figure 3-5):

$$F = G \times U + F0 \quad \text{(eq.2)}$$

With **F** the applied force, **U** the measured output voltage, the gain **G**=0.65N/V and the offset **F0**=-0.19N [28].

3.1.2. Inertial Measurement Unit

In order to capture the movement and to measure the accelerations and direction during the training sessions of the upper body of the rider and the bicycle frame, two sensors of the IMU type have been used .. One of the IMU is part of the wearable node attached to the athlete and the second one is mounted on the bicycle level.

IMU, is an electronic device that measures and reports velocity, orientation, and gravitational forces, using a combination of accelerometers, gyroscopes and magnetometer. The Pololu MinIMU-9 v3 used (Figure 3-6) is a compact board that combines ST's L3GD20H 3-axis gyroscope and LSM303D 3-axis accelerometer and 3-axis magnetometer to form an inertial measurement unit (IMU) [29].

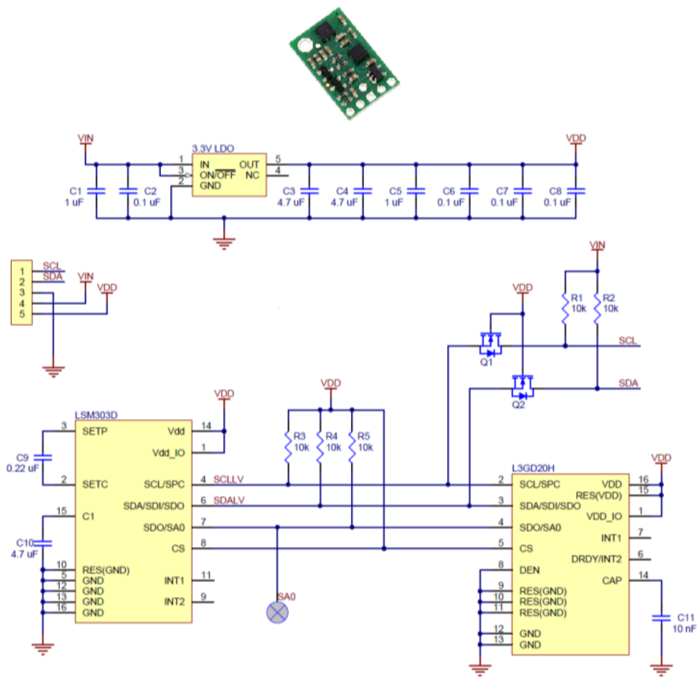


Figure 3-6 Pololu - MinIMU-9 v3 schematic diagram

The LSM303D [30] is a system-in-package featuring a 3D digital linear acceleration sensor and a 3D digital magnetic sensor. It includes an I2C serial bus interface that supports standard and fast mode 100 kHz and 400 kHz and SPI serial standard interface.

The L3GD20H [31] is a low-power three-axis angular rate sensor. It includes a sensing element and an IC interface able to provide the measured angular rate to the external world through digital interface (I2C/SPI).The sensing element is manufactured using a dedicated micromachining process developed by ST to produce inertial sensors and actuators on silicon wafers.

The nine independent rotation, acceleration, and magnetic readings (sometimes called 9 Degrees of Freedom) provide all the data needed to make an attitude and heading reference system (AHRS). AHRS consists of sensors on three axes that provide heading, attitude and yaw information.

This IMU has a measurement range of:

- ±245, ±500, or ±2000°/s (gyro)
- ±2, ±4, ±6, ±8, or ±16 g (accelerometer)
- ±2, ±4, ±8, or ±12 gauss (magnetometer)

3.1.3. GPS

A GPS receiver is used in coordinator node in order to make the tracking the route and collect the altimetry and speed of the athlete and the bike. The GPS receiver is materialized in a FGPMMOPA6H [32] that utilizes the MediaTek new generation GPS Chipset MT3339 that achieves the industry's highest level of sensitivity (-165dBm) and instant Time-to-First Fix (TTFF) with lowest power consumption for precise GPS signal processing to give the ultra-precise positioning under low receptive, high velocity conditions. FGPMMOPA6H is excellent low power consumption characteristic (acquisition 82mW, tracking 66mW), power sensitive devices, especially portable applications.

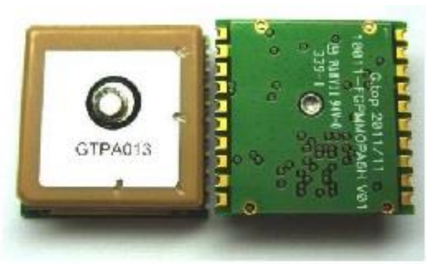


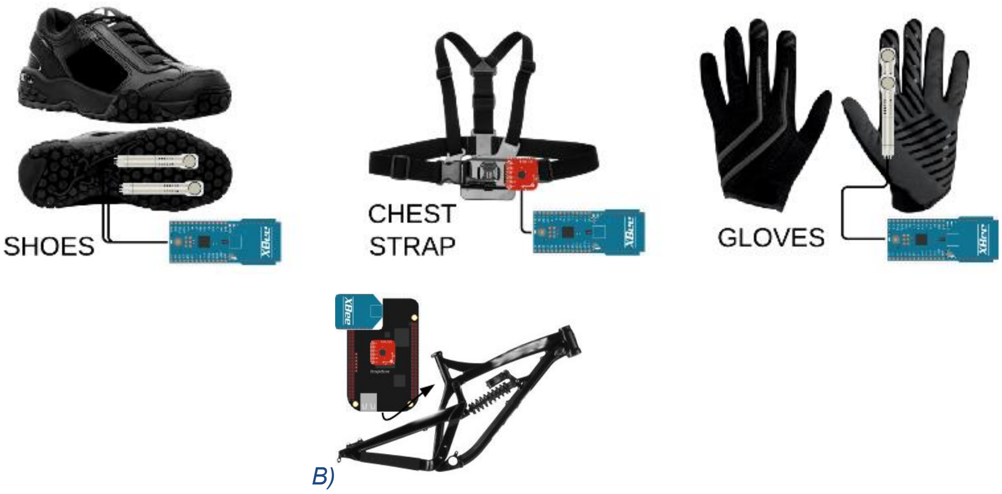
Figure 3-7 FGPMMOPA6H GPS Standalone Module

This receiver allows sensitivity values of -148 dBm (Acquisition) and -165 dBm (Tracking), is position accuracy without aid is 3.0 m), is TTFF (Time to First Fix) values are: Cold Start: <35 Seconds, Warm Start: <33 Seconds and Hot Start: <1 Seconds.

3.2. Acquisition and primary processing

Regarding the acquisition and primary processing of sensor data, two types of embedded systems are used: microcontrollers and embedded computer. As in Figure 3-8, the microcontrollers Arduino Fio are located in the end of the WSN nodes, ie, gloves, shoes and chest strap. While the coordinator of the WSN consists of a microcomputer.

A)



B)

Figure 3-8 A) End Nodes - Microcontrollers; B) Coordinator Node - Microcomputer

3.2.1. Microcontroller

The used microcontroller ATmega328P, is a high-performance Atmel picoPower 8-bit AVR RISC-based microcontroller. This device achieves throughputs approaching 1 MIPS per MHz, balancing power consumption and processing speed [33]. Each microcontroller is responsible for the acquisition of force sensor or IMU data, primary processing and communication of data to the network coordinator.

The Arduino Fio used is a microcontroller board based on the ATmega328P runs at 3.3V and 8 MHz, each of the 14 digital pins on the Fio can be used as an input or output and it has a number of facilities for communicating with a computer or other microcontrollers, including the ability to directly connect a XBee modem [34]. It has connections for a Lithium Polymer battery and includes a charge circuit over USB, so we opted to power the circuit with FullWat high discharge Li-Po battery with 3.7V nominal voltage and 1050 mAh capacity, model LP603450-CL [35].

The microcontroller is programmed using Arduino IDE [36], using C compiler language and Arduino libraries. Depending on the type of sensor have different ways of collecting and processing the data. In case of force sensors the circuit is assembled according to the schematic below (Figure 3-9):

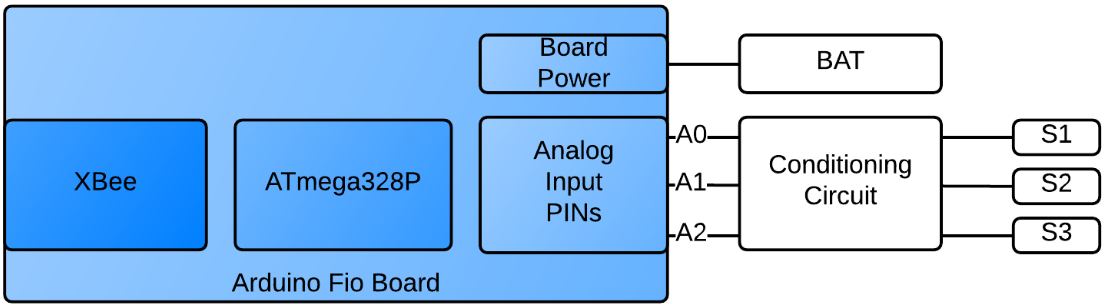


Figure 3-9 Microcontroller schematic - Arduino Fio board powered by LiPo battery and with conditioning circuit stacked and connected with force sensors (S1, S2, S3)

Explaining the diagram above, BAT is a lithium polymer battery that powers the circuit, S1, S2 and S3 are Flexiforce force sensors (3.1.1), these are connected to the conditioning circuit board which in turn is connected to the Arduino Fio Board.

Based on the equation of the conditioning circuit (eq.1), Vout is the read voltage at the analog input pin and its value (between 0 and 1023 due to analog-to-digital converter) is converted to a value of strength in Kg [37]. This conversion is expressed by the equation (eq.3):

$$F(Vout) = 10.56 * \left(\frac{adc_{value}}{4096*2.5}\right) \quad \text{(eq.3)}$$

The F(Vout) conversion in SI force units is given by (eq.4):

$$F(Vout)[N] = F(Vout)[Kg] * 9.8 \quad \text{(eq.4)}$$

After reading the sensors (2 sensors in the gloves and 3 sensors in shoes) and realize primary processing performed data is encapsulated in a packet to be sent over the network Zig Bee, network communications Zig Bee is detailed in the next section (3.3.1).

In case of IMU the circuit is assembled according to the schematic below (Figure 3-10):

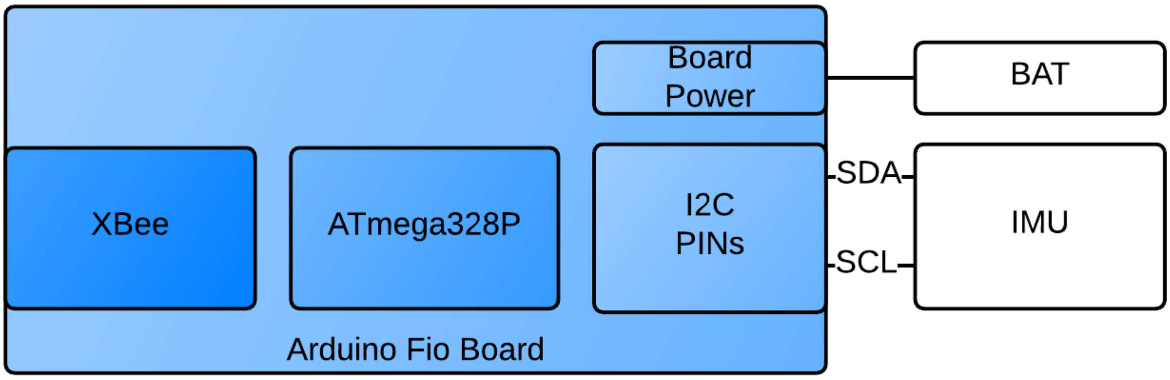


Figure 3-10 Microcontroller schematic - Arduino Fio board powered by LiPo battery and with IMU connected via I2C

Explaining the diagram above, BAT is a lithium polymer battery that powers the circuit and the IMU is the Pololu MinIMU-9 v3 used (Figure 3-6) that is connected to Arduino using 4 wires, 2 for the I2C (A4 - SDA and A5 – SCL), ground, and 3.3V. The microcontroller is programmed using the Arduino IDE, the program was based on an Arduino program (sketch) provided by Pololu's allow an Arduino connected to a minimu-9 v3 to function to an attitude and heading reference system (AHRS), calculating estimated roll, pitch, and yaw angles from sensor readings. This program processes the raw rotation, acceleration, and magnetic data from the minimu-9 to derive an estimate of the board's absolute orientation making use of Arduino and Pololu's L3G LSM303 libraries.

L3G library for the Arduino interfaces with the LSM303D, LSM303DLHC, LSM303DLM, and 3D compass and accelerometer I2Cs LSM303DLH. It makes it simple to read the raw accelerometer and magnetometer data.

LSM303 library for the Arduino interfaces with the L3GD20H, L3GD20, and L3G4200D gyros on Pololu boards. It makes it simple to read the raw gyro data.

This program had slight changes, such as setting the rate for transmission 9600baud. Initially the program read the raw accelerometer and magnetometer data, and process the tilt-compensated heading for the LSM303 compass, this data is sent using Serial Arduino library to communicate with Xbee module.

3.2.2. Embedded Computer

The central module has 5 functions, collect information from IMU (3.1.2) to identify the movement of the bike, collect data from the other nodes of WSN (3.3.1) via XBee module, connect GPS (3.1.3) for geographic information, connect to the mobile network (3.3.2) to send the information collected and write to the SD card data backup.

Initially the central network node located in the bicycle frame it was materialized by an embedded computer BeagleBone Black with a 1GHz AM335x ARM® Cortex-A8 processor from Texas Instruments Incorporated [38] with a GPS / GPRS Cape that added GPS and GSM/GPRS capabilities to the BeagleBone for tracking and M2M communication. That cape use the Telit GE864 [39] module and supported the Quad band GSM/GPRS (850MHz, 900MHz, 1800MHz and 1900MHz). However it was not possible to proceed with this solution due to constant errors in mobile network authentication.

To solve this problem opted for a Arduino Mega 2560 [40] with a Arduino GSM Shield [41] that connects Arduino to the internet using the GPRS wireless network. The shield uses a radio modem M10 [42] by Quectel [43] that supports HTTP protocols through a GPRS connection. The M10 is a Quad-band GSM/GPRS modem works at frequencies GSM850MHz, GSM900MHz, DCS1800MHz and PCS1900MHz.

However, this solution was also not viable because the Arduino GSM shield and Adafruit GPS Shield have compatibility issues in terms of hardware (pins used) and in terms of software (libraries used). Even after the changes recommended by the manufacturers was not possible to implement this solution.

The third solution was to maintain the use of the Arduino Mega 2560 to read the IMU, data from the sensor network, data from the GPS receiver and write to the SD card while it communicates data through Serial port so that other microcomputer handle the communication with the mobile network.

Arduino Mega 2560 used is a microcontroller board based on ATmega2560 [44], it is a low-power CMOS 8-bit microcontroller based on the AVR enhanced RISC architecture. By executing powerful instructions in a single clock cycle, the ATmega2560 achieves throughputs approaching 1 MIPS per MHz allowing the system designed to optimize power consumption versus processing speed. This board has useful features such as

54 digital input/output pins of which 4 are UARTs (hardware serial ports) used to receive (RX) and transmit (TX) TTL serial data, 4 SPI pins (MISO, MOSI, SCK and SS) and 2 pins (SDA - Serial Data Line and SCL - Serial Clock Line) for I2C communication. In the following figure (Figure 3-11) got the schematic assembly of the central module:

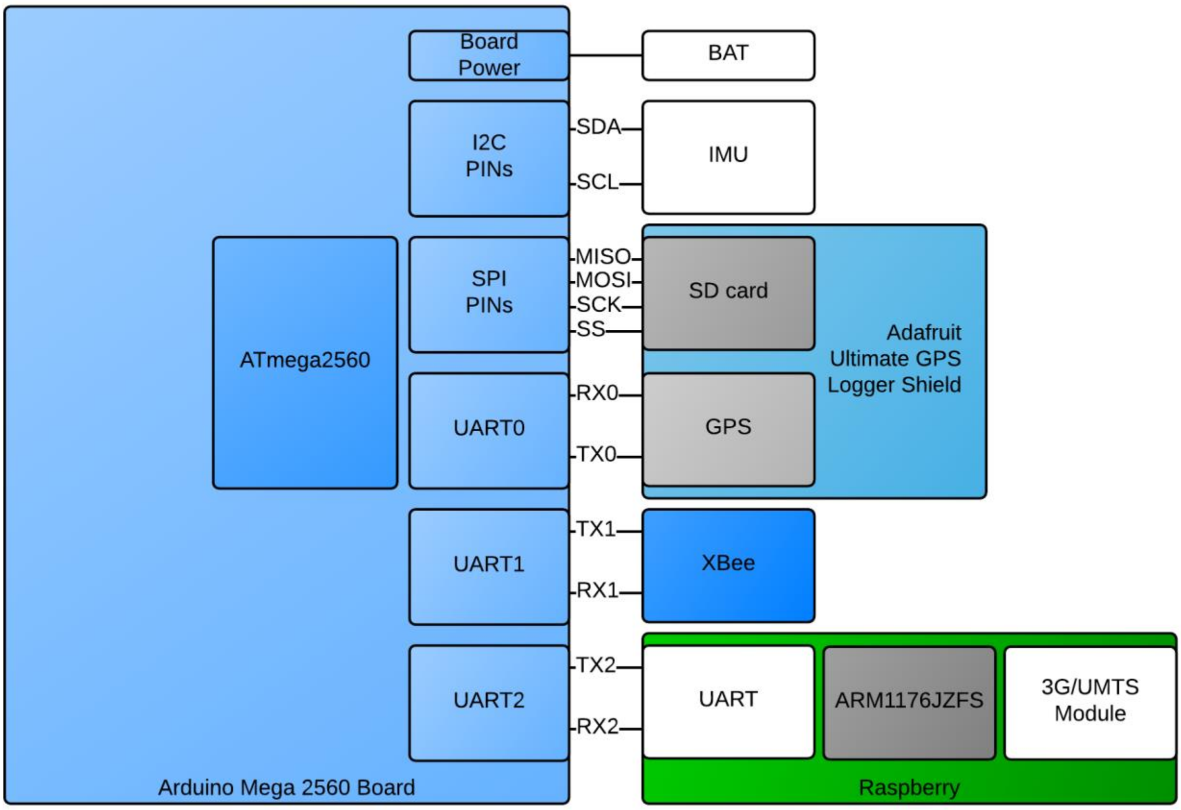


Figure 3-11 Microcontroller Arduino Mega and Raspberry PI

Starting with the Arduino board, the board is powered by two batteries (BAT) 9V rechargeable connected in parallel. The communication with the IMU module is based on the I2C protocol and is exactly the same as described in section 3.2.1. The GPS receiver (3.1.3) is embedded in an Arduino compatible logger shield that has a port for the SD card that allows the system to back up all the data collected.

As we can see in Figure 1, the 3G / UMTS communication is made by the Raspberry Pi microcomputer, the Raspberry Pi Model B [45] is used, this model has a 700 MHz Low Power ARM1176JZ-F [46] Applications Processor, serial port pins to communicate with Arduino Mega 2560 and also USB port to connect the 3G/UMTS Module.

The Xbee module and the 3G/UMTS module will be further described in the next chapter.

3.3. Communication

Regarding communication, we have two main protocols, ZigBee between network nodes and GSM/GPRS between the coordinator node and the Cloud.

3.3.1. Zig Bee Network

The communication between the network nodes is done through a network Zig Bee, for that we have an XBee® 802.15.4 S1 [10] module coupled to each microcontroller and to the embedded computer. XBee RF modules are embedded solutions providing wireless end-point connectivity to devices. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or peer-to-peer networking and they are designed for high-throughput applications requiring low latency and predictable communication timing.

The three flexible topologies for network construction are star, tree, and mesh respectively (Figure 3-12).

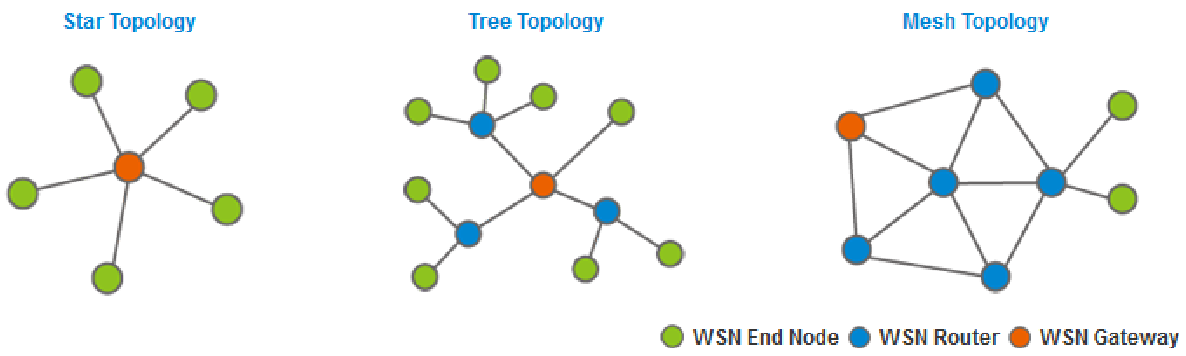


Figure 3-12 - WSN Topologies

All ZigBee networks must have one (and only one) Coordinator Node or WSN Gateway, irrespective of the network topology. In the Star topology, the Co-ordinator is the central node in the network and in the Tree and Mesh topologies, the Co-ordinator is the top (root) node in the network. The main tasks of an End Device at the network level are sending and receiving messages. The main tasks of a Router is relay messages from one node to another.

As can be seen in the Figure 3-13, the network has a star topology, in which the embedded computer placed in bicycle frame represents the WSN coordinator and the end nodes are placed in gloves, shoes and chest strap.

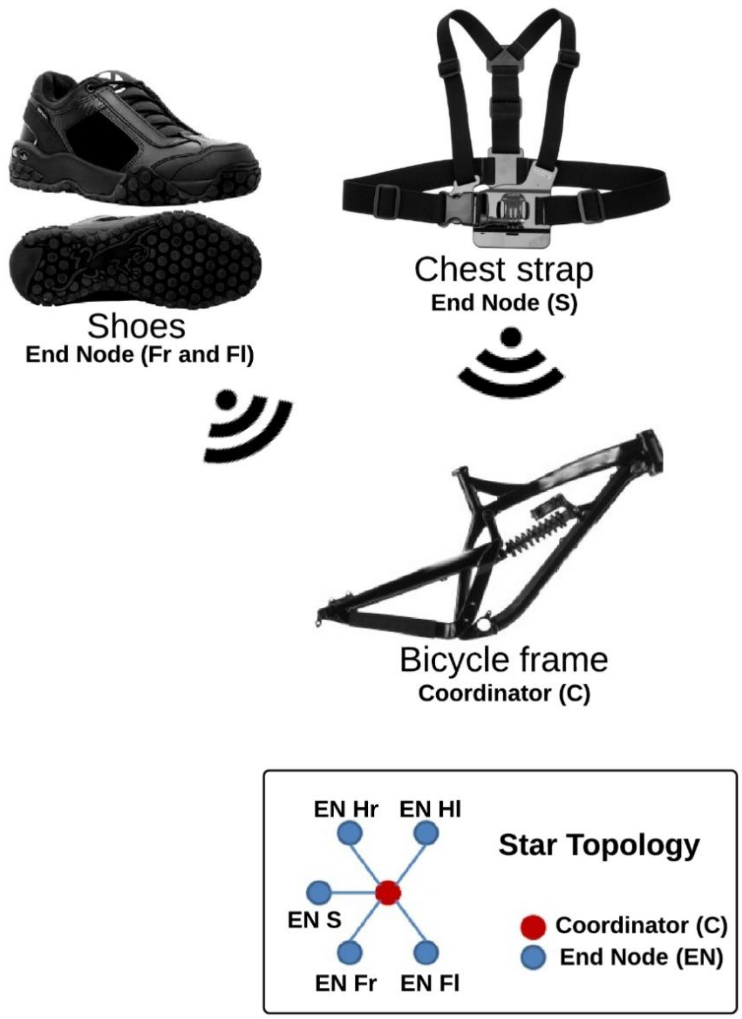


Figure 3-13 WSN Star Topology. End Nodes: Fr - Foot Right, FL - Foot Left, S - Chest Strap, Hr - Hand Right and Hl - Hand Left, and Coordinator (C)

XCTU Software [47] was used to configure all XBee® 802.15.4 modules. XCTU is a free multi-platform application designed to enable developers to interact with Digi RF modules through a simple-to-use graphical interface. It includes new tools that make it easy to set-up, configure and test XBee® RF modules. Main configurations made on each XBee module are: PAN ID to identify the network, the Destination Address Destination Address High and Low to distinguish the network nodes and the baud rate of all nodes is 9600baud.

Figure 3-14 shows the format of packets sent by the End Nodes to the coordinator node. There are three types of packets, distinguished by the node generating the packet containing a unique ID.

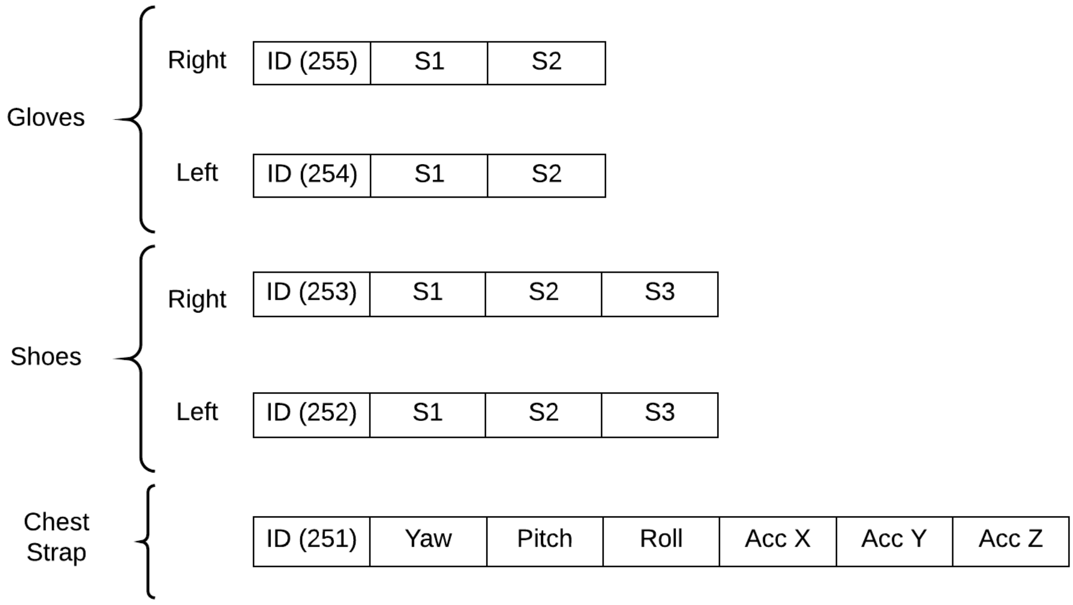


Figure 3-14 Packages End nodes

Explaining the figure above, the packet generated in the End Node Gloves has a fragment for each of the two force sensors (S1 and S2) placed on the finger brake, the packet generated in the End Node Shoes has a fragment for each of the three force sensors (S1, S2 and S3) distributed on the sole of the shoe, and finally the packet generated in the end Node Chest strap has a fragment for each of the data from the IMU. The fragments are yaw, pitch, roll and acceleration in 3 plans of motion.

3.3.2. M2M Communication

In this scenario the term Machine-to-Machine refers to communication via mobile networks from the coordinator of the WSN node with the database hosted in the cloud. This architecture allows without human interaction information collected is stored and processed in the cloud.

For this, the coordinator node is the gateway of WSN, the connection with the server in the cloud is done through a mobile internet modem. The modem used is a Huawei E220 [48], it is a Huawei HSDPA access device manufactured by Huawei and notable for using the USB interface. This modem is used for wireless Internet access using 3.5G, 3G, or 2G mobile telephony networks and it supports UMTS (including HSDPA), EDGE, GPRS and GSM.

After the connection is established the mobile network, the data collected by WSN are sent through HTTP requests to write into the database. The HyperText Transfer (HTTP) protocol is a set of standards that enable communications between clients and servers and it works as a request-response protocol between a clients and servers. The PHP scripts are further detailed in section 4.2.

3.4. Conclusions

A distributed system architecture was developed and implemented, a special attention was granted for embedded programming as well as Wireless Sensor Network implementation.

Referring WSN design specialized nodes were implemented in wearable version. Thus a set of smart gloves and smart shoes provide information about dynamic and kinematic quantities. A patent application on the architecture of the project and possible uses in other scenarios was developed. The patent is currently under evaluation (Appendix C).

The WSN coordinator works as smart gateway providing primary processing and mobile network capability with 2G, 3G and 3,5G technologies.

4. Cloud

Cloud computing is offline computing in which large groups of remote servers are networked to allow the centralized data storage, and online access to computer services or resources, so that the server has a LAMP environment installed (Figure 4-1).

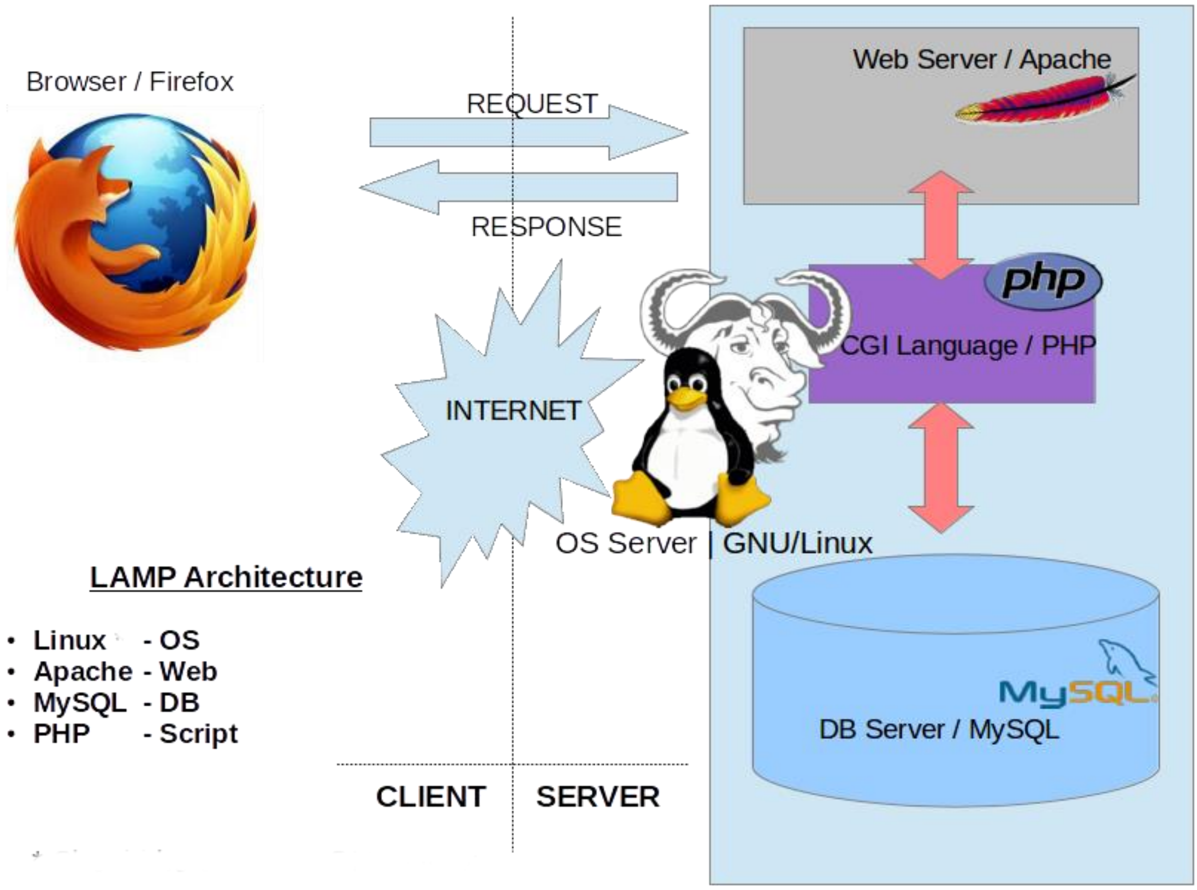


Figure 4-1 LAMP Architecture

LAMP [49] is an acronym for a model of web service solution stacks, originally consisting of largely interchangeable components: Linux OS, the Apache HTTP Server, the MySQL relational database management system, and the PHP programming language. The server runs a Linux Ubuntu 12.04.4 LTS operating system with an Apache HTTP Server 2.2.22. In this chapter we detail the structure of the database and the PHP scripts needed for communication.

4.1. Database

The database is required to store all system data, this includes the WSN sensor data and mobile application data. In this case been designed a database which is based on three items, the user, user training, and the training data.

To design, structure and manage the database use the MySQL Workbench tool [50]. MySQL Workbench is a visual database design tool that Integrates SQL development, administration, database design, creation and maintenance into a single integrated development environment for the MySQL database system [51]. MySQL, is the most popular Open Source SQL database management system, is developed, distributed, and supported by Oracle Corporation.

Figure 4-2, shows the model developed for object-relational database (ORD), the objects and its relations are explained below.

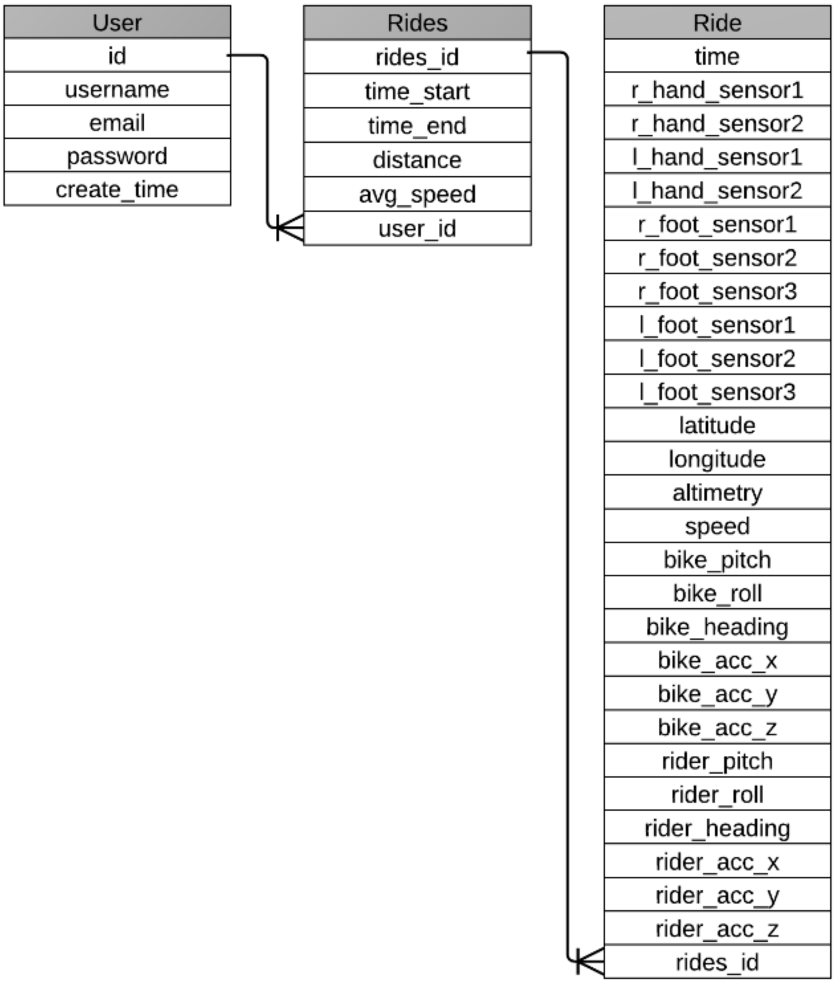


Figure 4-2 Database Model Diagram

Objects

- **User** - Rider or coach, this object stores information needed for authentication in application such as email, username and password, and each user is distinguished by its ID.
- **Rides** - List of training sessions, this table allows to structure the list of training sessions for each athlete in order to distinguish the training sessions.
- **Ride** - training data, this table stores the values collected by sensors throughout the workout session.

Relations

- **User / Rides** - Each user has a list of training sessions.
- **Rides / Ride** - Each session has a set of training data collected over time.

4.2. PHP Module

To handle the reading and writing in the database, PHP scripts were developed using Medoo PHP database framework [52]. The Medoo framework is compatible with various SQL databases including MySQL, support various common and complex SQL queries, is safe against SQL injection attacks, is lightweight (one file - 14KB) and is Free - Under MIT license.

The following php files are hosted on the server:

- **medoo.php** - contains all data configurations required to connect to the database as user, pass, server type and server location, and also a set of functions used by the scripts presented below.

The scripts postline and postride are used to write into the database, and are required through an HTTP request sent by the coordinator of the WSN.

- **postline.php** - adds a row to the table Ride with the information from the sensors, force, IMU and GPS, and the timestamp in which these data were collected.
- **postride.php** - adds a row to the table Rides with the information of the training session, at the end of the training session are sent timestamps start and end as

well as some data already processed by the central node as the average speed and the percentage of use of each hand.

The scripts login, getrideslist and getridedata are used to read from the database, and are required through an HTTP request sent by the mobile application.

- **login.php** - receives the user name and password inserted on the app, and checks if the user exists in the database if it exists and then checks whether the password corresponding to the user.
- **getrideslist.php** - given a user ID, the script returns all corresponding training sessions as well as some data such as the date and duration of the training.
- **getridedata.php** - given a training ID, the script returns all data from sensors, force, IMU and GPS, as well as the timestamp of each data collection.

4.3. Conclusions

To summarize this section, there are three main topics, the Linux, Apache, MySQL and PHP (LAMP) architecture, the network database model and PHP Module.

The LAMP architecture has several advantages, including architectural stability and reliability of unix and unix-derived operating systems, fast server side scripting technology and high performance database interaction, Extensive complementary tools and library support, built-in security Measures of stack members, simplicity of deployment and coding and is cost-effective.

Now focusing in the advantages of using the network database model. Some advantages include conceptual simplicity, data access flexibility, conformance to standards, handle more relationship types and promote promotion database integrity.

Using PHP technology a set of write and read operation on database were implemented in order to permit the storage of the WSN data on the database and to allow the access to these data from the implemented mobile application that will be described in the next chapter.

5. Mobile Application

The goal of the mobile application is to allow the user to view the data collected in different trainings conducted with Smart Bike Prototype. The mobile application was developed primarily targeting tablets with Android operating system version 4.2.0 (Jelly Bean). Taking into account the connection to the Cloud, the device necessarily requires internet connection either via WiFi or via mobile network (3G, 4G).

5.1. Sequence Diagram

The sequence of activities in an application is represented in the following diagram:

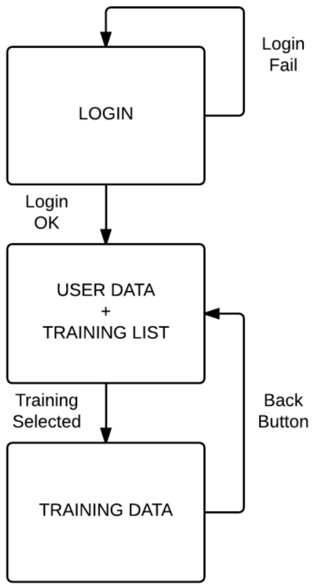


Figure 5-1 Activity sequence Diagram

The login activity connects to the server and checks if the user exists and entered the credentials correctly. If "login fail" the application prompts the reason, or the user does not exist or has been misspelled, or the password does not match the user. If "login ok" starts a new activity called user data, that shows the user data (for instance, name, age, weight, height), it also shows the data of the bicycle (for instance, model on the brakes, suspensions and frame) and a list of training performed is displayed with some information such as the date and distance in order to distinguish the training sessions.

The training data activity shows all the information about the training session chosen in the previous activity. Is divided into four sections, training information, map visualization, video player and sensor data.

5.2. Design and implementation

The application was developed for the purpose of having a simple and intuitive interface, design standards have been respected. The app was developed from scratch starting by the custom logo and application icon (Figure 5-2).

Figure 5-2 "Smart Mountain Bike" Mobile Application Icon

When taped the icon and application is started, the Login activity is launched. As seen in Figure 5-3, this is where the user make is authentication writing his e-mail and password in the text areas showed above.

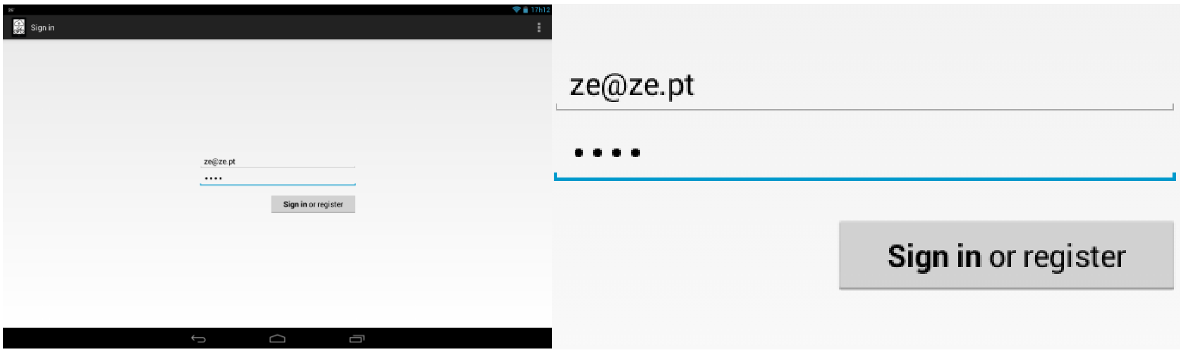


Figure 5-3 "Smart Mountain Bike" Mobile Application Login Activity Layout

After a successful authentication, the Rides activity is launched. As seen in Figure 5-4, the layout consists of 3 areas, user data, bicycle date, and training list. User data bicycle and date, exhibit user and bicycle avatar respectively, and also displays in a tabular form all data. The table training list is displayed so that the user can select the training he wants to see in detail.

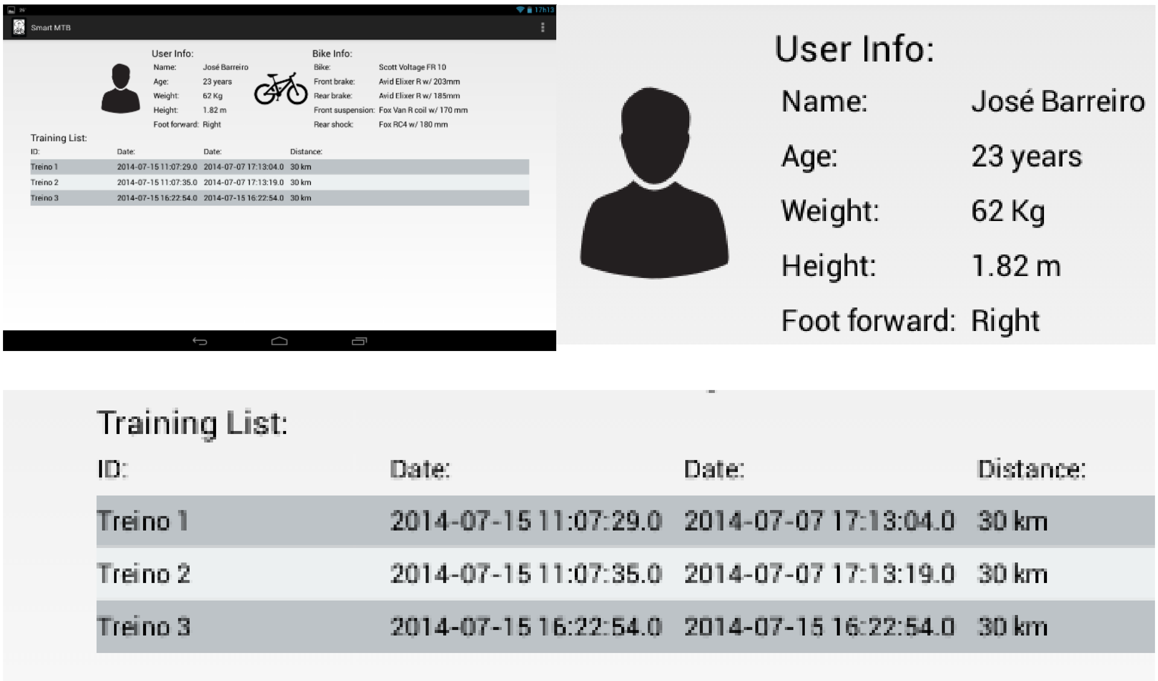


Figure 5-4 "Smart Mountain Bike" Mobile Application Rides Activity Layout

After a training session chosen in training list, the Ride activity is launched.

As seen in Figure 5-5, the layout contains 5 sections, the layout contains five areas, map view, track info, video player, sensor data, and correlated data.

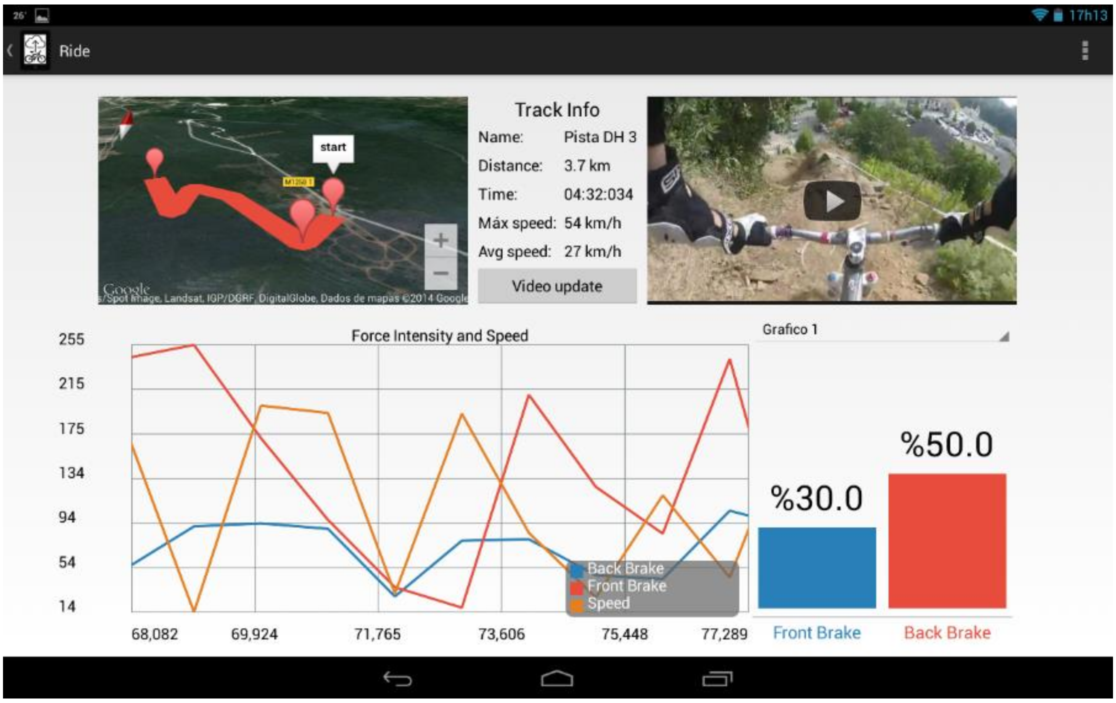


Figure 5-5 "Smart Mountain Bike" Mobile Application Ride Activity Layout

The features of each section of the application will be explained in the next section.

5.3. Application Main Features

- Communication with Cloud – Application communicates with the database through HTTP requests using the Volley library. Volley [53] is an HTTP library that makes networking for Android apps easier and most importantly, faster. Volley offers the following benefits:
    - Automatic scheduling of network requests.
    - Transparent disk and memory response caching with standard HTTP cache coherence.
- Secure authentication - the application implements an authentication mechanism in order to protect user data. This mechanism is based in username and password to identify the user and login into the application.
- Graphic Sensor Data - The application shows the user data collected by sensors through a line graphs, using GraphView (Figure 5-6 A)) [54] library. This library allows draw multiple series of data that allows display to the user multiple sensor data. Another advantages are scroll with a finger touch move gesture and two-fingers touch scale gesture that allow the user to explore and analyse the graphic.

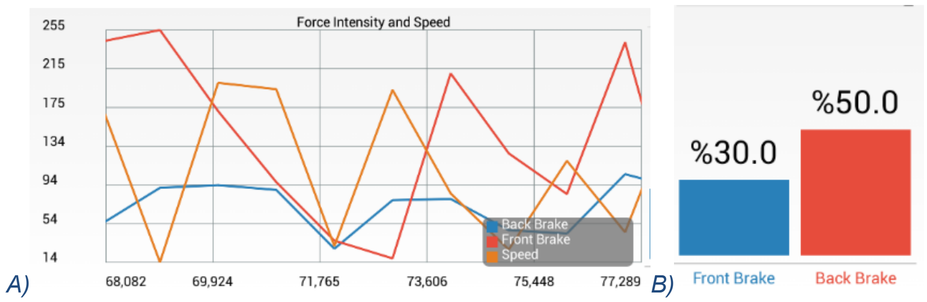


Figure 5-6 Mobile Application - Graphics Libraries

  To display bar charts, Holographlibrary (Figure 5-6 B)) [55] library is used. This type of chart is used to demonstrate the comparison of two percentages, the percentage of use of the rear brake vs the front brake.

- Map view - This allows the user to see the route of the training and points of interest, such as start and end point. A satellite view of the map is made using the API provided by google, called Google Maps Android API v2 [56]. This is done using the coordinates, latitude and longitude, received by the GPS receiver (143.1.3) connected to the WSN coordinator node.

- Video player - This allows the user to see the YouTube video (if recorded) after the user enters the ID of the video in the application. The video view is made using the API provided by google, called YouTube Android Player API [57].

5.4. Conclusions

Summarizing this chapter, the developed mobile application allows you to view the history of all trainings performed and in each training allows you to view information gathered by wireless sensor network almost immediately.

Comparing with other existing mobile applications on the market, this is the only one that has an associated WSN and present and process the data stored on the the cloud level. A special attention granted to the mobile application GUI in order to assure extended information from de sensors and processed data on the client side.

6. Evaluation

The tests of the individual nodes and WSN was done developing, a Java application using Processing [58]. This JAVA application runs on a PC with an XBee Explorer that receive all the information of network nodes placed in shoes and gloves, and allows their visualization in real time as well as its storage in a file that can later be analyzed in a spreadsheet application such as Excel.

Initially the user chooses the test name and file where the data is stored (Figure 6-1).

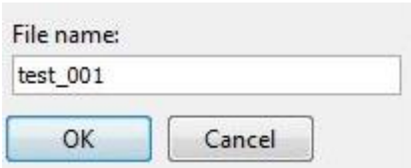


Figure 6-1 Processing Application – Filename

The connection to the XBee explorer is performed via USB, in the following menu the user can choose the USB port to be used (Figure).

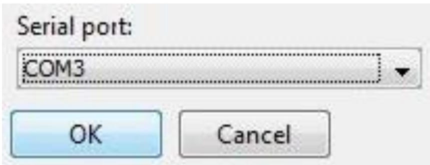


Figure 6-2 Processing Application – Serial Port

After establishing communication, the application will listen is the serial port. The information collected can be viewed in real time, and can be analysed later through a text file. Figure 6-3 shows a photo of the working system to test the sensor gloves.

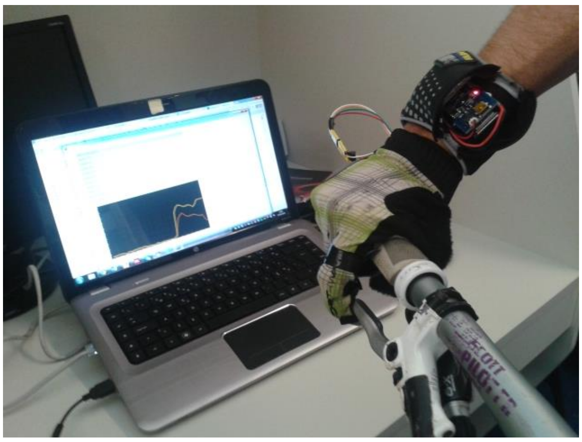


Figure 6-3 Processing Application – Testing

The conditioning of the sensors cannot interfere with the natural movement of cycling and has to be comfortable to use. With this in mind, the conditioning solution shown in Figure 6-4was developed.

Figure 6-4 Prototype Smart Mountain Bike System

For mobile nodes, hands (A) and feet (B), storage pockets have been adapted to carry in a compact form the microcomputer board (Arduino FIO) and the sensors conditioning circuit, and the battery. For the fixed node, bicycle frame (C), a box was developed to store safely and compactly all components of the coordinator node.

This test was performed in the same conditions of any track mountain bike, climb and descent, and rough terrain with jumps. To achieve a benchmark and analyse the data, three repetitions of the course starting and ending at the same point were performed.

In the following section are demonstrated and discussed all the results.

6.1. Results

The test presented takes about 3 minutes and it was performed in a circular mountain bike track. During the test several variables were collected, they are:

- GPS – Latitude, Longitude, Altimetry and Speed.
- Force Sensors – Force applied on brakes and pedals.
- IMU – Motions and accelerations in three plan of motion.

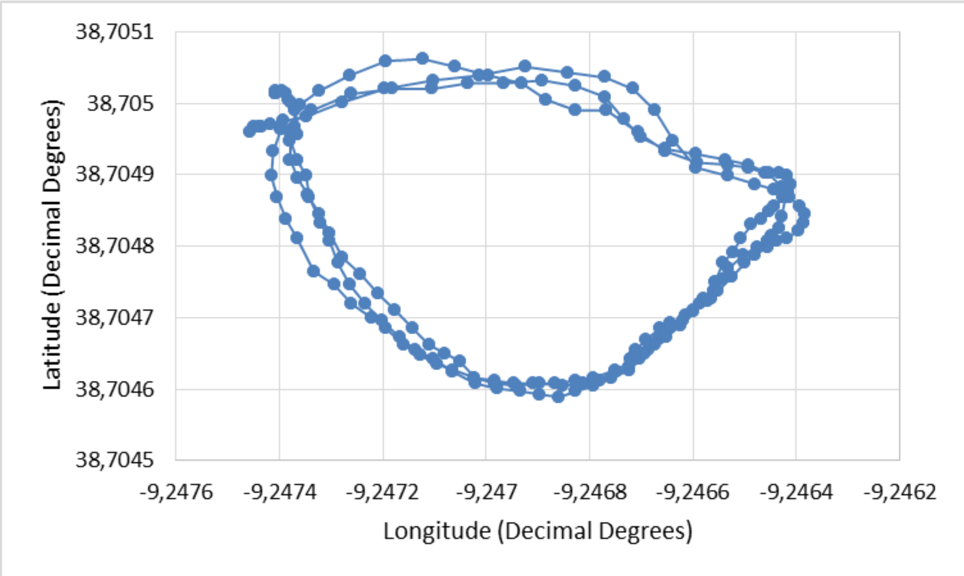


Figure 6-5 GPS Tracking, Latitude and Longitude

Figure 6-6 Map view, GPS Tracking, Latitude and Longitude

Considering Figure 6-5 shows that the GPS coordinates obtained during the test, are clearly perceptible to three laps completed. Figure 6-6 was generated to verify the accuracy of the results in Figure 6-5, the satellite views help in the identification of the track.

Saving the trajectory (Figure 6-5) and the corresponding speed it is possible to identify the sections of track that are faster and slower. In Figure 6-7 is showed the section that has top speed in all three laps, another conclusion is that the speed increases with the lap, this is explained because if the athlete knows better the terrain he will go faster.

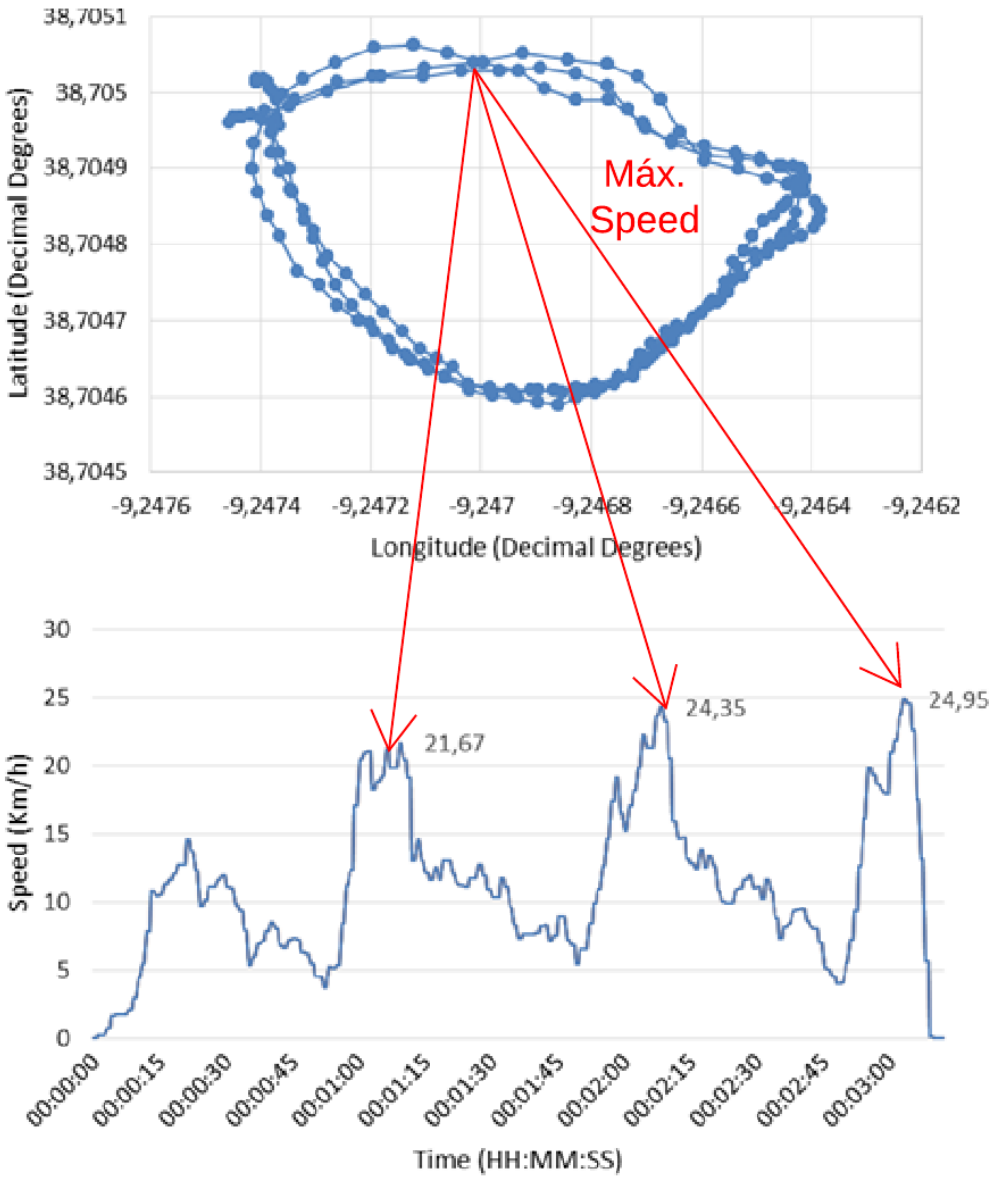


Figure 6-7 Speed variation during 3 laps

In Figure 6-8 is presented the values measured by the IMU while the athlete is turning left, is visible that the bike undergoes an inclination to the left and then back to the normal position.

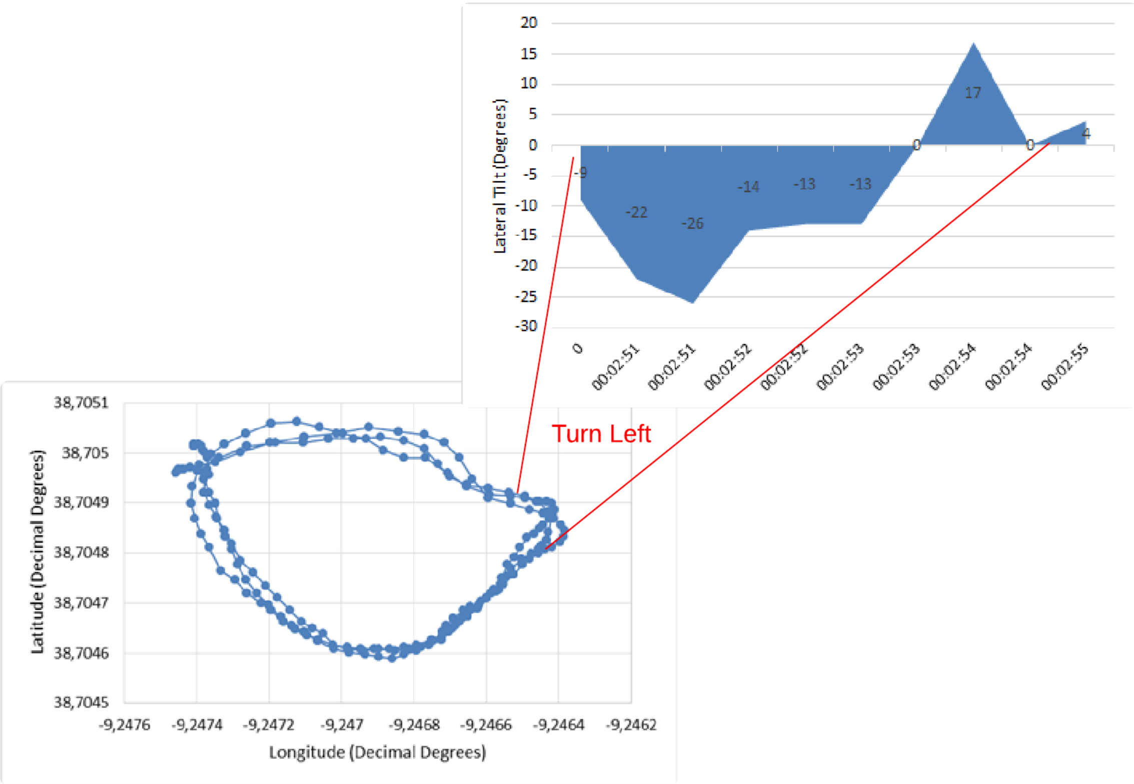


Figure 6-8 - Lateral tilt turning left

From Figure 6-9 it is observable that the athlete on each lap makes uphill and downhill, the downhill section corresponds to the top speed section as expected.

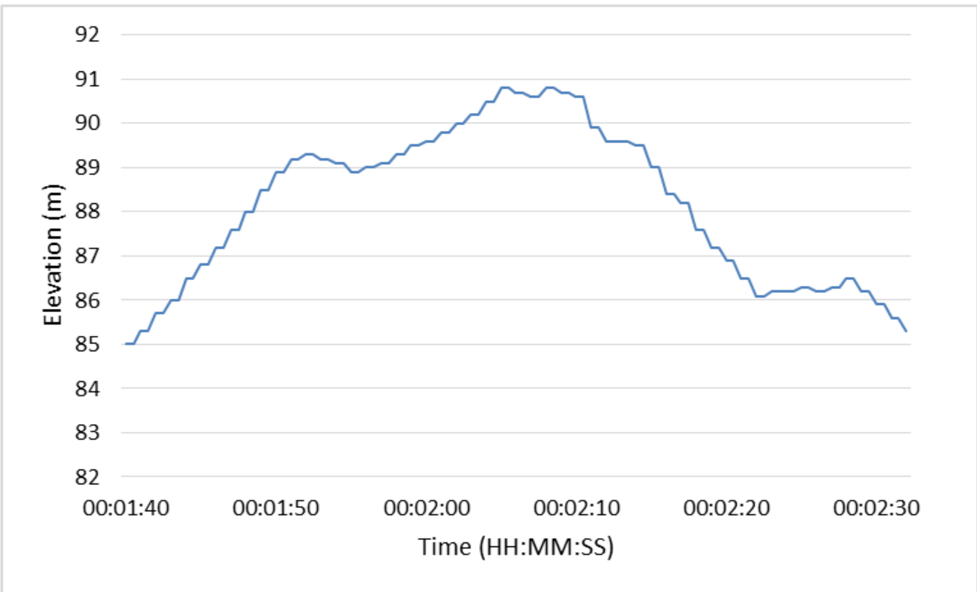


Figure 6-9 - Altimetry (1 Lap)

Now focusing on the information collected by the sensors of force, Figure 6-12 shows the values of force applied to the brake, although some saturation can make visible a statistical analysis of the data as demonstrated in Figure 6-11 where it is shown the percentage of use of the brakes, ie, corresponding to the left hand front brake, and vice versa.

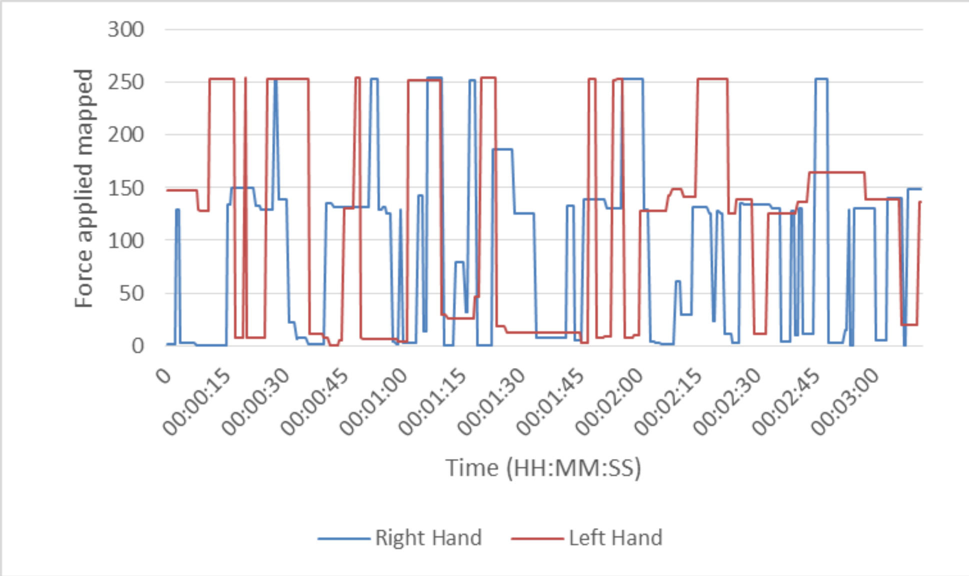


Figure 6-10 Force Applied - Right and Left Hand Sensor Data

Rear brake (Right Hand) is used 60.36% of total training time and on the other hand is 64.77%.

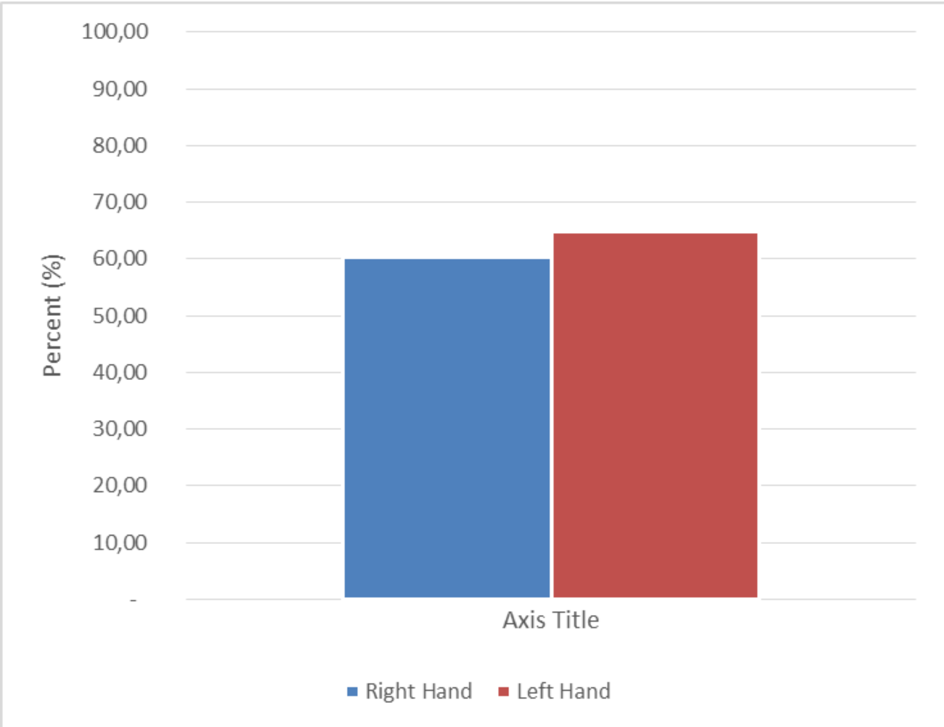


Figure 6-11 Force Applied - Right and Left Foot Statistic Data

Following a similar analysis to the above logic. For the sensor data of force applied to the pedals shown in Fig 1, is visible to the right foot exerts more force on the pedal for almost the entire route.

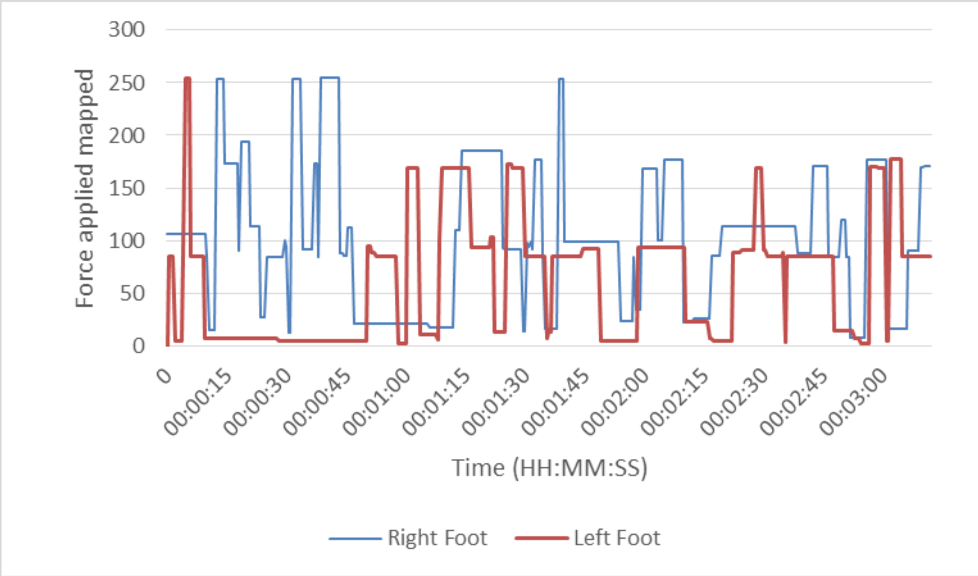


Figure 6-12 Force Applied - Right and Left Foot Sensor Data

The previous statement is proven by the analysis of the percentage of time that force is exerted on the pedal. In Figure 3 we can see that the right foot corresponds to 74.87% and 54.40% left foot.

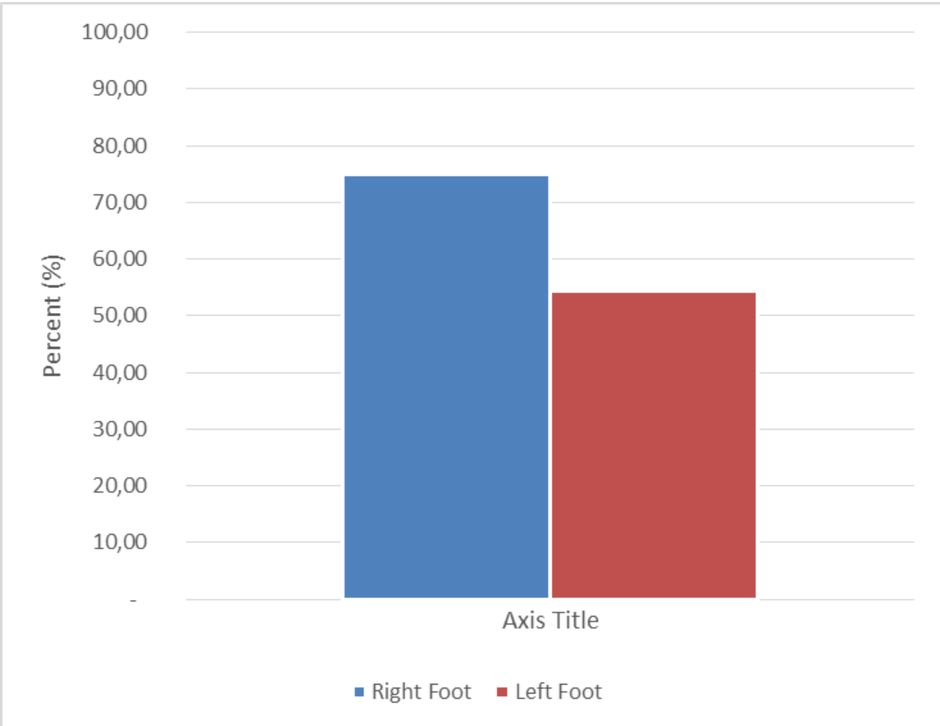


Figure 6-13 Force Applied - Right and Left Hand Statistic Data

7. Conclusions

The scope of the dissertation was the integration of the Wireless Sensor Network and embedded programming concepts to materialize a “smart bike” prototype.

Therefore, was developed and implemented a system architecture that merges embedded systems, as sensing nodes, in a wireless sensor network, to provide distributed sensing and processing. The WSN’s nodes were implemented in wearable version, concretely smart gloves and smart shoes, which provide information about dynamic and kinematic quantities. The WSN nodes communicate with the WSN coordinator that was developed to work as a smart gateway, providing primary processing and mobile network capabilities through the use of mobile technologies, as 2G or 3G.

In the cloud is used a LAMP architecture. By the use of this LAMP architecture exists advantages in terms of architectural stability and reliability of unix and unix-derived operating systems, fast server side scripting technology and high performance database interaction, extensive complementary tools, library support and built-in security. The communication between the WSN coordinator and the database is achieved with the usage of PHP technology, which allows writing and reading operation.

This approach was the advantages of conceptual simplicity, data access flexibility, conformance to standards, handle more relationship types and promote promotion database integrity.

Finally, it was developed a mobile application, for Android based devices, which allows viewing the history of all trainings or analyzing the information about each one, which was gathered by the WSN.

The proposed system has the advantage of be a complete solution than other applications in the market, since it includes an associated WSN and storage and processes the data in the cloud, while providing the data visualization through a mobile application.

To summarize, the system's architecture comprises the embedded hardware, to perform the measurements; the database, to storage the users' training data in the cloud; and the mobile application, to access, visualize and analyses the training data.

7.1. Contributions

This dissertation offers as original contributions the design and implementation of the "Smart Mountain Bike" system, which uses a WSN and M2M communication for cycling performance assessment.

During the elaboration of this dissertation the following paper (Appendix A) was published:

Barreiro J., Postolache O., and Passos P., “WSN and M2M for cycling performance assessment”, Eighth International Conference on Sensing Technology, Liverpool John Moores University, UK, September, 2-4, 2014

And a poster (Appendix B) was presented in same conference.

A patent application on the architecture of the project and possible uses in other scenarios was developed. The patent is currently under evaluation (Appendix C)

7.2. Future work

This prototype solution was designed from scratch so the prototype developed is functional but could care for more improvements.

Such as improving the conditioning of end nodes and add an external switch to turn on / off each node. Improvements can also be made at the level of the coordinator node on trying to optimize the communication with the server in order to obtain the data in real-time mode with the shortest possible delay.

At the application level there are several correlations of data to be exploited for the moment the application only demonstrates the data and makes little analysis as calculating the percentage of use of the right or left hand. In addition to the correlation between variables can be also explored the development of another type of graphics to display information including the comparison of training performed.

8. References

[1] P. S. Girão, P. M. P. Ramos, O. Postolache, and J. Miguel Dias Pereira, “Tactile sensors for robotic applications,” *Measurement*, vol. 46, no. 3, pp. 1257–1271, Apr. 2013.

[2] Y.-K. Kong and B. D. Lowe, “Optimal cylindrical handle diameter for grip force tasks,” *Int. J. Ind. Ergon.*, vol. 35, no. 6, pp. 495–507, Jun. 2005.

[3] L. Liu, Y.-G. Bai, D.-L. Zhang, and Z.-G. Wu, “Ultra-precision measurement and control of angle motion in piezo-based platforms using strain gauge sensors and a robust composite controller.,” *Sensors (Basel).*, vol. 13, no. 7, pp. 9070–84, Jan. 2013.

[4] N. Ahmad, R. A. R. Ghazilla, N. M. Khairi, and V. Kasi, “Reviews on Various Inertial Measurement Unit (IMU) Sensor Applications,” *Int. J. Signal Process. Syst.*, vol. 1, no. 2, pp. 256–262, 2013.

[5] “What is GPS? Everyday Mysteries.” [Online]. Available: http://www.loc.gov/rr/scitech/mysteries/global.html. [Accessed: 08-Oct-2014].

[6] “NIST Time and Frequency Transfer using Common-View GPS.” [Online]. Available: http://web.archive.org/web/20121028043917/http://tf.nist.gov/time/commonviewgps.htm. [Accessed: 28-Oct-2014].

[7] M. G. Rodriguez, L. E. O. Uriarte, Y. Jia, K. Yoshii, R. Ross, and P. H. Beckman, “Wireless Sensor Network for Data-Center Environmental Monitoring,” pp. 533–537, 2014.

[8] X. H. Le, S. Lee, P. Tran, H. Truc, L. T. Vinh, A. M. Khattak, M. Han, V. Hung, M. M. Hassan, M. H. Kim, K. Koo, Y. Lee, and E. Huh, “Secured WSN-integrated Cloud Computing for u-Life Care,” pp. 1–2, 2010.

[9] N. S. A. Zulkifli, F. K. C. Harun, and N. S. Azahar, “XBee Wireless Sensor Networks for Heart Rate Monitoring in Sport Training,” no. in C.

[10] Digi International Inc., “XBee® 802.15.4 - Digi International.” [Online]. Available: http://www.digi.com/products/wireless-wired-embedded-solutions/zigbee-rf-modules/point-multipoint-rfmodules/xbee-series1-module. [Accessed: 28-May-2014].

[11] C. Bujdei and S. A. Moraru, “A low cost framework designed for monitoring applications, based on Wireless Sensor Networks,” *2012 13th Int. Conf. Optim. Electr. Electron. Equip.*, pp. 1211–1220, May 2012.

[12] N. W. Bergmann, M. Wallace, E. Calia, I. Superiore, and M. Boella, “Low Cost Prototyping System for Sensor Networks,” pp. 19–24, 2010.

[13] R. In, “M2M : From Mobile to Embedded Internet,” no. April, pp. 36–43, 2011.

[14] Y. Chen, “S7-1 Challenges and Opportunities of Internet of Things S7-1,” pp. 383–388, 2012.

[15] G. K. Thiruvathukal and M. Parashar, “Cloud Computing [Guest editorial],” *Comput. Sci. Eng.*, vol. 15, no. 4, pp. 8–9, Jul. 2013.

[16] P. Mell and T. Grance, “The NIST Definition of Cloud Computing Recommendations of the National Institute of Standards and Technology.”

[17] A. Alamri, W. S. Ansari, M. M. Hassan, M. S. Hossain, A. Alelaiwi, and M. A. Hossain, “A Survey on Sensor-Cloud: Architecture, Applications, and Approaches,” *Int. J. Distrib. Sens. Networks*, vol. 2013, pp. 1–18, 2013.

[18] “Gartner Says Annual Smartphone Sales Surpassed Sales of Feature Phones for the First Time in 2013.” [Online]. Available: http://www.gartner.com/newsroom/id/2665715. [Accessed: 09-Oct-2014].

[19] G. Anthes, “Invasion of the mobile apps,” *Commun. ACM*, vol. 54, no. 9, p. 16, Sep. 2011.

[20] W. COLDWELL, “The 10 Best iPhone and Android cycle apps - Features - Gadgets & Tech - The Independent,” 2013. [Online]. Available: http://www.independent.co.uk/life-style/gadgets-and-tech/features/the-10-best-iphone-and-android-cycle-apps-8567728.html. [Accessed: 26-Jan-2014].

[21] “Best iPhone and Android apps for cycling - BikeRadar.” [Online]. Available: http://www.bikeradar.com/gear/article/best-iphone-and-android-apps-for-cycling-35227/. [Accessed: 09-Oct-2014].

[22] “Strava Cycling - GPS Riding - Android Apps on Google Play.” [Online]. Available: https://play.google.com/store/apps/details?id=com.strava&hl=en. [Accessed: 27-Jan-2014].

[23] “Abvio | Cyclemeter.” [Online]. Available: https://abvio.com/cyclemeter/. [Accessed: 09-Oct-2014].

[24] “Portugal Cycling - Routes, Trails, Groups, Events and Races.” [Online]. Available: http://www.mapmyride.com/pt/. [Accessed: 09-Oct-2014].

[25] S. B. L. in U. of California, “Instrumented Bicycle — Sports Biomechanics Lab.” [Online]. Available: http://biosport.ucdavis.edu/research-projects/bicycle/instrumented-bicycle. [Accessed: 20-Jan-2014].

[26] D. Lie and C.-K. Sung, “Synchronous brake analysis for a bicycle,” *Mech. Mach. Theory*, vol. 45, no. 4, pp. 543–554, Apr. 2010.

[27] Tekscan, “FlexiForce® Force Sensors | Single Button Force Sensing Resistor | Tekscan.” [Online]. Available: http://www.tekscan.com/flexible-force-sensors#third. [Accessed: 23-Apr-2014].

[28] C. Lebosse, B. Bayle, M. De Mathelin, and P. Renaud, “Nonlinear modeling of low cost force sensors,” *2008 IEEE Int. Conf. Robot. Autom.*, pp. 3437–3442, 2008.

[29] “Pololu - MinIMU-9 v3 Gyro, Accelerometer, and Compass (L3GD20H and LSM303D Carrier).” [Online]. Available: http://www.pololu.com/product/2468/resources. [Accessed: 02-Jun-2014].

[30] “LSM303D.” [Online]. Available: http://www.pololu.com/file/0J703/LSM303D.pdf. [Accessed: 09-Oct-2014].

[31] “L3GD20H.” [Online]. Available: http://www.pololu.com/file/0J731/L3GD20H.pdf. [Accessed: 09-Oct-2014].

[32] “FGPMMOPA6H.” [Online]. Available: http://www.adafruit.com/datasheets/GlobalTop-FGPMMOPA6H-Datasheet-V0A.pdf. [Accessed: 09-Oct-2014].

[33] Atmel, “ATmega328P,” 2014. [Online]. Available: http://www.atmel.com/devices/atmega328p.aspx?tab=overview. [Accessed: 16-May-2014].

[34] “Arduino - ArduinoBoardFio.” [Online]. Available: http://arduino.cc/en/Main/ArduinoBoardFio. [Accessed: 09-Sep-2014].

[35] “High discharge / 5C - 10C | Fullwat.” [Online]. Available: http://en.fullwat.com/high-discharge-5c-10c/. [Accessed: 10-Oct-2014].

[36] “Arduino - Software.” [Online]. Available: http://arduino.cc/en/main/software. [Accessed: 11-Sep-2014].

[37] “Tekscan® A201-100 - Advantic System.” [Online]. Available: http://www.advanticsys.com/wiki/index.php?title=Tekscan®_A201-100. [Accessed: 29-May-2014].

[38] Texas Instruments Incorporated, “AM3358 | AM335x Processors | ARM Cortex-A8 Core | Description & parametrics.” [Online]. Available: http://www.ti.com/product/am3358. [Accessed: 28-May-2014].

[39] “GE864-GPS - Telit.” [Online]. Available: http://www.telit.com/products/product-service-selector/product-service-selector/show/product/ge864-gps/. [Accessed: 09-Sep-2014].

[40] “Arduino - ArduinoBoardMega2560.” [Online]. Available: http://arduino.cc/en/Main/arduinoBoardMega2560. [Accessed: 10-Oct-2014].

[41] “Arduino - ArduinoGSMShield.” [Online]. Available: http://arduino.cc/en/Main/ArduinoGSMShield. [Accessed: 14-Oct-2014].

[42] “Quectel Cellular Engine - M10.” [Online]. Available: http://arduino.cc/en/uploads/Main/Quectel_M10_datasheet.pdf. [Accessed: 14-Oct-2014].

[43] “Quectel Wireless Solutions - Dedicated M2M Wireless Module Supplier.” [Online]. Available: http://www.quectel.com/. [Accessed: 14-Oct-2014].

[44] “ATmega2560 datasheet.” [Online]. Available: http://www.atmel.com/Images/Atmel-2549-8-bit-AVR-Microcontroller-ATmega640-1280-1281-2560-2561_datasheet.pdf. [Accessed: 10-Oct-2014].

[45] “Model B | Raspberry Pi.” [Online]. Available: http://www.raspberrypi.org/products/model-b/. [Accessed: 30-Oct-2014].

[46] “DDI0301H_arm1176jzfs_r0p7_trm.pdf.” [Online]. Available: http://infocenter.arm.com/help/topic/com.arm.doc.ddi0301h/DDI0301H_arm1176jzfs_r0p7_trm.pdf. [Accessed: 30-Oct-2014].

[47] “XCTU - Digi International.” [Online]. Available: http://www.digi.com/products/wireless-wired-embedded-solutions/zigbee-rf-modules/xctu. [Accessed: 11-Sep-2014].

[48] “What is the specification for the Huawei E220 USB modem?” [Online]. Available: https://www.business.vodafone.com/site/bus/public/enuk/support/10_productsupport/05_vmc_usb_modem/02_huawei/05_huawei_e220/faq/p_faq303_usbmod.jsp. [Accessed: 30-Oct-2014].

[49] “LAMP (Linux, Apache, MySQL, PHP),” *SearchEnterpriseLinux*.

[50] “MySQL :: MySQL Workbench.” [Online]. Available: http://www.mysql.com/products/workbench/. [Accessed: 08-Sep-2014].

[51] “MySQL :: The world’s most popular open source database.” [Online]. Available: http://www.mysql.com/. [Accessed: 08-Sep-2014].

[52] “About Medoo.” [Online]. Available: http://medoo.in/about. [Accessed: 08-Sep-2014].

[53] “Transmitting Network Data Using Volley | Android Developers.” [Online]. Available: http://developer.android.com/training/volley/index.html. [Accessed: 11-Sep-2014].

[54] “Android GraphView - official Project Homepage.” [Online]. Available: http://android-graphview.org/. [Accessed: 11-Sep-2014].

[55] “danielnadeau / HoloGraphLibrary — Bitbucket.” [Online]. Available: https://bitbucket.org/danielnadeau/holographlibrary. [Accessed: 11-Sep-2014].

[56] “Google Maps Android API v2 — Google Developers.” [Online]. Available: https://developers.google.com/maps/documentation/android/?hl=fr-FR. [Accessed: 26-May-2014].

[57] “YouTube Android Player API - YouTube — Google Developers.” [Online]. Available: https://developers.google.com/youtube/android/player/. [Accessed: 26-May-2014].

[58] “Processing.org.” [Online]. Available: http://processing.org/. [Accessed: 11-Sep-2014].

Appendix A

Article

WSN and M2M for cycling performance assessment

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Abstract— **Cycling assessment to increase performance during sport training. In this condition the article presents a wireless sensor network including multi-sensing channels for dynamic and cinematic measurement during cycling training. The Smart Mountain Bike is a system that include the bicycle and the associated sports equipment, such as gloves, shoes and chest strap. The system is characterized by sensing channels as part of wireless sensor network which base station is expressed by embedded computer and a 3G/UMTS shield which permit the data communication with a cloud server. The data stored on the server is accessed through a mobile application that analyzes and correlates all user information and allows data visualization with a friendly graphical interface.**

wireless sensor network; machine-to-machine; bicycle; cloud; mobile application

I. Introduction

Mountain bikes are typically ridden on single track trails and other unpaved environments. These types of terrain commonly include rocks, loose gravel, roots, and steep grades (both inclines and declines) which demands a continuously adaptation from the rider aiming to achieve a tiny balance between speed and safety. Mountain bikes are built to handle this terrain and the obstacles that are found in it like logs, vertical drop offs, and smaller boulders. Along the trail the rider controls the bike through the hands, feet and body positioning. Thus going down a track in mountain bike demands a close interaction between rider and bicycle which is highly constrained by external factors such as the track slope and obstacles. It is that interactive behavior between bicycle and rider that we aim to capture, using IMU and force sensors as part of wireless sensor network (WSN). For that purpose on a first stage data collection is performed using the following variables: i) braking intensity; ii) braking frequency; iii) pedal strength; iv) rider body positioning; v) bicycle oscillations on the three plans of motion. These variables allow calculate coordinative variables to describe rider – bicycle interactions.

Training is critical to the performance of any athlete, whether professional or recreational. The "Smart Mountain Bike" system will allow recreational practitioners, as well as athletes and their respective coaches to obtain new performance data and consecutively adapt the training methods and improve sports performance.

II. Related Work

Cycling is a complex physical activity that involves a broad set of movements. This movement can be studied using instrumented bikes [1]. The placement of sensors on the bike parts and equipment allows us to collect other information such as the applied force and accelerations. This type of study allows the creation of models that describe the movement and balance. Research in this field especially related to analysis of synchronous braking on a bicycle are reported in [2].

In recent years, advances in wireless sensor networks (WSN) have facilitated the use of these networks for monitoring applications, and there are some low-cost frameworks used as [3], [4]. One of the areas on the rise is the monitoring of indoor [5] and outdoor [6] environmental conditions, and other area is the monitoring of the human body in various disciplines such as health monitoring [7] or analyzing sports performance [8].

Another expanding area is communication Machine-to-Machine (M2M) [9], [10] mainly due to mass use of the Internet and the ability to connect new devices to the network, this leads us to the evolution of the Internet of Things (IoT) and the creation of new opportunities and challenges [11]. In is scenario, Cloud Computing [12] is a new paradigm that provides computing power, storage and software services and a scalable virtualized manner.

Joining WSN and Cloud Computing, the Sensor-Cloud architecture arises. This architecture allows to store and process the sensor data in accessible form, available timely, and cost-effective [13] [7]. It also allows easier integration with new mobile devices like tablets or smartphones through customized mobile applications that can collect, process and display all sensor data.

Currently thousands of mobile applications are placed on the market every day [14], some of these apps are related to the use of bicycles and cycling but, most of these only collect information via mobile phone modules (GPS, accelerometer and gyroscope) and in some cases also through a Bluetooth external heartbeat sensor [15].

In this context, the paper presents a system that collects data on cycling activity through a WSN sending the primary processed data via M2M communication, stores them in the cloud, and analyzes them through a mobile application.

III. SMART MOUNTAIN BIKE: OVERVIEW

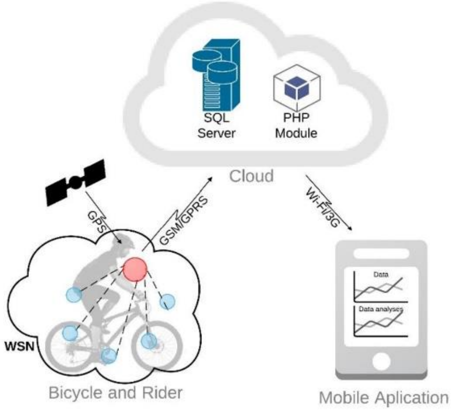

Figure. 1 - System overview. A) Bicycle and Rider include data collection trough WSN and GPS receiver. B) Cloud storage with a SQL server. C) Mobile Application to visualize and analyze cloud-sensor data.

The "Smart Mountain Bike" system consists of three blocks (Fig. 1). The first, called Bicycle and Rider consists of a wireless sensors network where sensors are placed on sports equipment such as gloves, shoes, chest strap and bicycle frame. Each of the end nodes have a ATmega328P microcontroller to make the acquisition and processing of primary data, this is then sent to the network core that consists of an embedded computer that handles the communication with the server that materialize the cloud. The second block consists of a server with a SQL database to ensure the storage of all information collected and to perform the advanced signal processing of the data. Finally, the data allocated on the server is accessed through a mobile application, developed for Android OS that analyzes and correlates all user information and allows data visualization through a friendly graphical user interface.

IV. SMART MOUNTAIN BIKE: HARDWARE

The WSN hardware responsible for the acquisition, processing and delivery of data to the cloud are force sensors, inertial measurement units including 3G accelerometer[16] , microcontrollers [17] and embedded computer [18].

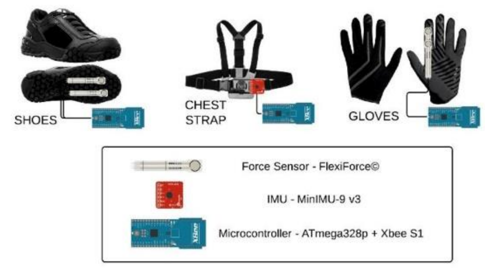

Figure. 2 – Sensors and Microcontroller nodes

A. Sensors and conditioning circuits

1) Force sensors

The force sensor (Figure. 3) is materialized by a flexible piezoresistor included in a voltage divider implementation.. When the force sensor is unloaded, its resistance is very high the output of conditioning circuit being zero while when a force is applied to the sensor, the sensor resistance decrease [19].

Figure. 3 - FlexiForce® a201 100lbs

The conditioning circuit voltage output increasing (Fig 4). These sensors are used in gloves and shoes to measure the force applied to the brakes and pedals respectively. The following conditioning circuit is used:

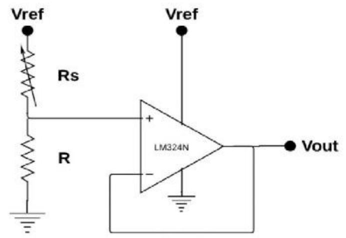

Figure. 4 - Conditioning circuit for force sensors

The conditioning circuit output voltage is given by::

$$Vout = \frac{R}{Rs+R} \times Vref \qquad (1)$$

where, the parameters in equation (1) are defined as follows:
Vref: is the reference voltage [V];
Rs: is the variable resistance, force sensor [Ω];
R: is the reference resistor [Ω];
Vout: is the output voltage [V];

2) Inertial measurement unit

IMU, is an electronic device that measures and reports velocity, orientation, and gravitational forces, using a combination of accelerometers, gyroscopes and magnetometer. The Pololu MinIMU-9 v3 used (Figure. 5) is a compact board that combines ST's L3GD20H 3-axis gyroscope and LSM303D 3-axis accelerometer and 3-axis magnetometer to form an inertial measurement unit (IMU).

Figure. 5 - Pololu - MinIMU-9 v3

The nine independent rotation, acceleration, and magnetic readings (sometimes called 9 Degrees of Freedom) provide all the data needed to make an attitude and heading reference system (AHRS). AHRS consists of sensors on three axes that provide heading, attitude and yaw information.

These sensors are attached to the chest strap and measure the upper body motion. Attached to the bicycle frame it permit to monitor bicycle oscillations on the three plans of motion. The IMU, L3GD20H's gyro and the LSM303D's accelerometer and magnetometer can be queried and configured through the I²C bus. Each of the three sensors acts as a slave device on the same I²C bus.

B. Embedded systems

The ATmega328P is a high-performance Atmel picoPower 8-bit AVR RISC-based microcontroller. This device achieves throughputs approaching 1 MIPS per MHz, balancing power consumption and processing speed [17].

Each microcontroller is responsible for the acquisition of sensor data (Figure. 2), primary processing and communication of data to the network coordinator. The communication between the network nodes is done through a network Zig Bee, for that we have an XBee® 802.15.4 [20] module coupled to each microcontroller and to the embedded computer.

IEEE 802.15.4/ ZigBee sensor network support low power consumption and node expansion compared to other network standards for WSN [21].. As can be seen in the Figure. 6, the network has a star topology, in which the embedded computer placed in bicycle frame represents the WSN coordinator.

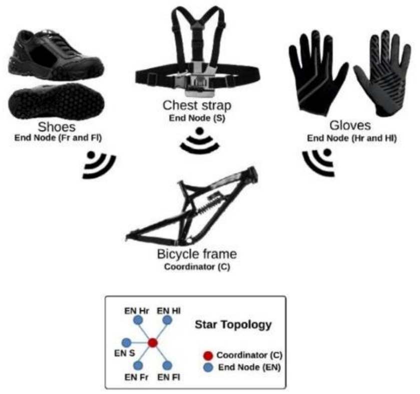

Figure. 6 – WSN start topology. Coordinator placed in bicycle frame. End nodes placed in shoes, chest strap and gloves.

C. Embedded computer

The central network node located in the bicycle frame it is materialized by an embedded computer BEAGLEBONE Black with a 1GHz AM335x ARM® Cortex-A8 processor from Texas Instruments Incorporated [18]. It also has a GPS / GPRS Cape that adds GPS and GSM/GPRS capabilities to the BeagleBone for tracking and M2M communication. The cape uses the Telit GE864 module and supports the Quad band GSM/GPRS (850MHz, 900MHz, 1800MHz and 1900MHz). Coupled to the embedded computer is also an IMU (IV.A.2) for measurement of bicycle frame oscillations on the three plans of motion.

V. SMART MOUNTAIN BIKE: SYSTEM SOFTWARE

Referring the software components several components are mentioned: the embedded microcontroller and microcomputer software, the database software that handles requests to the database and the mobile device software .

A. Embebbed software for microcontroller

The microcontroller is programmed using C compiler language and several Arduino libraries. The used data acquisition rate is 20samples/s. Depending on the type of sensor have different ways of collecting and processing the data are mentioned:

- In the case of force sensors, Vout (1) is the read voltage at the analog input pin and its value (between 0 and 1023 due to analog-to-digital converter) is converted to a value of strength in Kg [22]. This conversion is expressed by the equation (2):

$$F(Vout) = 10.56 * \left(\frac{adc_{value}}{4096 * 2.5}\right) \quad (2)$$

The F(Vout) conversion in SI force units is given by (3):

$$F(Vout)[N] = F(Vout)[Kg] * 9.8 \quad (3)$$

- In the case of the IMU, the L3GD20H and LSM303D each have separate slave addresses on the I²C bus. Pololu has written a basic L3GD20 and LSM303 Arduino library that allows the reading of the gyroscope, accelerometer and magnetometer registers therefore there is not necessary additional calculations in the microcontroller.

After this first processing the data is sent to the central node of the WSN with its identifier.

B. Microcomputer embebbed software

The microcomputer runs an Angstrom Linux operating system and is programmed using node.js and bonescript library.

This module gathers information from the IMU, GPS module and all other nodes in WSN, and establishes communication to cloud, to write the data in the database.

C. Cloud software

In the cloud we have two modules, SQL server with database and a module for PHP functions.

The database stores all the information about the user and his training, we have implemented the following model (Figure. 7).

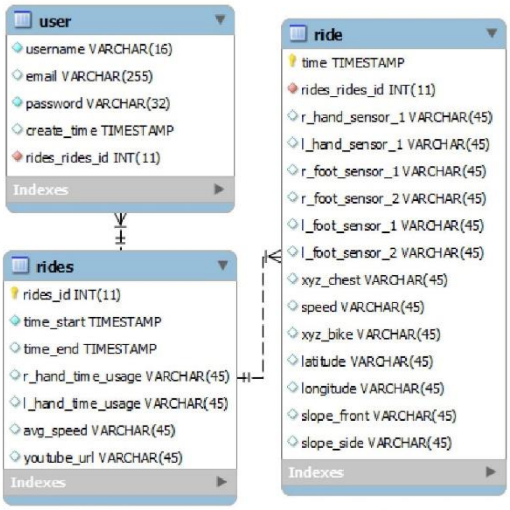

Figure. 7 - Database model including Users, List of trainings (Rides) e training session (Ride) with all sensor data.

The functions implemented in PHP allow read and write to the database using HTTP requests. Some functions are LOGIN.php, GETRIDES.php and GETRIDE.php. Mobile applicationThe mobile application was developed primarily targeting tablets with Android operating system version 4.2.0 (Jelly Bean). Taking into account the connection to the Cloud, the device necessarily requires internet connection either via WiFi or via mobile network (2G, 3G).The sequence of activities in an application is represented in the following diagram:

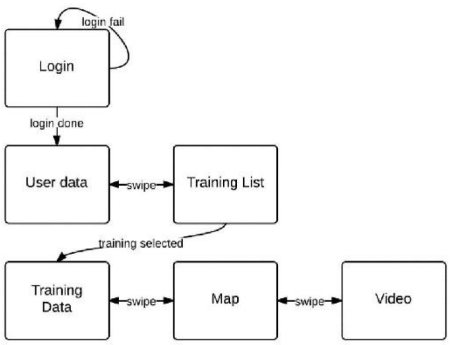

Figure. 8 - Application sequence diagram

The login activity connects to the server and checks if the user exists and entered the credentials correctly, if "login done" starts a new activity that shows the user data through according with the collected information about training.

This information includes braking intensity data and frequency braking in each hand; pedal strength for each foot; rider body positioning and 3D bicycle oscillations.

The user can visualize the information for each training session by selecting one from the list, this selection will start a new activity that shows three tabs:

- Data Tab - This tab displays the data analyzed through graphs and also allowing the user to view detailed information about the raw data corresponding to the graph.
- Map Tab - This Tab allows the user to see the route of the train and points of interest, such as zone of maximum and minimum speed. A satellite view of the map is made using the API provided by google, called Google Maps Android API v2 [23].
- Video Tab - This Tab allows the user to see the YouTube video (if recorded) after the user enters the ID of the video in the application. The video view is made using the API provided by google, called YouTube Android Player API [24].

VI. PRELIMINARY AND DISCUSSIONS

For the tests of the individual nodes and WSN, an application was developed in Java using Processing. This application runs on a PC with an XBee Explorer that receive all the information of network nodes placed in shoes and gloves (Figure. 9), and allows their visualization in real time as well as its storage in a file that can later be analyzed in a spreadsheet application such as Excel.

Figure. 9 - Shoe and Glove force sensors

The prototype is still being assembled but we have collected some exemplar data. Exploratory data collection was performed using force sensors in right foot and right hand.

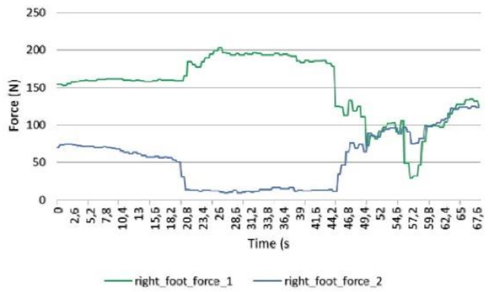

Figure. 10 – Force evolution while rider is mounted on the bike testing variations in horizontal slope

Data collection was performed with the rider on the bike, and varying the bike inclination on the sagittal plan of motion under three conditions: i). bike with upright position; ii) bike tilted to the right; iii) bike tilted to the left.

The following data chart display rider behavior with the bike stopped in upright position. Due to no brakes action the red line remains with values close to 0. It is worth noting that due to the rider behavior to maintain a stable position on the bike the sensors from both feet capture fluctuations in the force produced.

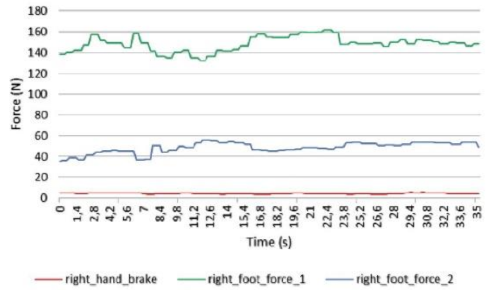

Figure. 11 - Force evolution while rider is mounted on the bike stable

With the rider sitting on the bike and the right hand on the brake, testing multiple braking action. Data display the magnitude and frequency of several force peaks which correspond to the different braking events.

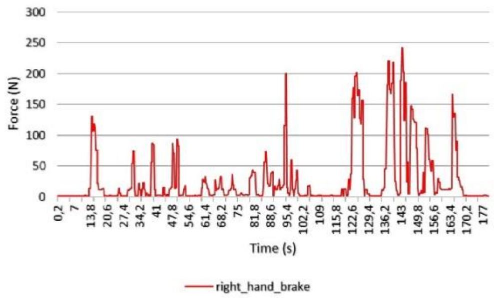

Figure. 12 - Force evolution applied by the fingers for multiple breaking tests

The mobile application is still in development but already has some active features, such as geographic information system (Figure. 13) and an embedded YouTube video player (Figure. 14).

Figure. 13 - App geographic information system

Figure. 14 - App embedded YouTube video player

Some tests are being done to determine what the best type of chart to display the information collected and analyzed. In Figure. 15, we have an example of a pie chart on the use of brakes, comparing the left hand with the right hand.

Figure. 15 - App chart type test, hands usage information

VII. Conclusions and Future Work

In the paper the general architecture hardware and software of smart mountain bike prototype is presented including elements of WSN for force, direction acceleration measurement during the training session. As well as a first version of a database and the mobile application.

Additional results concerning the training parameters calculated through the acquired values from the sensors will be included in the final version of the paper

Acknowledgements

This work was supported by the Instituto de Telecomunicações and Fundação para a Ciência e Tecnologia Special acknowledgement is granted.

References

[1] S. B. L. in U. of California, "Instrumented Bicycle — Sports Biomechanics Lab." [Online]. Available: http://biosport.ucdavis.edu/research-projects/bicycle/instrumented-bicycle. [Accessed: 20-Jan-2014].

[2] D. Lie and C.-K. Sung, "Synchronous brake analysis for a bicycle," Mech. Mach. Theory, vol. 45, no. 4, pp. 543–554, Apr. 2010.

[3] N. W. Bergmann, M. Wallace, E. Calia, I. Superiore, and M. Boella, "Low Cost Prototyping System for Sensor Networks," pp. 19–24, 2010.

[4] C. Bujdei and S. A. Moraru, "A low cost framework designed for monitoring applications, based on Wireless Sensor Networks," 2012 13th Int. Conf. Optim. Electr. Electron. Equip., pp. 1211–1220, May 2012.

[5] M. G. Rodriguez, L. E. O. Uriarte, Y. Jia, K. Yoshii, R. Ross, and P. H. Beckman, "Wireless Sensor Network for Data-Center Environmental Monitoring," pp. 533–537, 2014.

[6] C. Yu, Y. Cui, L. Zhang, and S. Yang, "ZigBee Wireless Sensor Network in Environmental Monitoring Applications," 2009 5th Int. Conf. Wirel. Commun. Netw. Mob. Comput., pp. 1–5, Sep. 2009.

[7] X. H. Le, S. Lee, P. Tran, H. Truc, L. T. Vinh, A. M. Khattak, M. Han, V. Hung, M. M. Hassan, M. H. Kim, K. Koo, Y. Lee, and E. Huh, "Secured WSN-integrated Cloud Computing for u-Life Care," pp. 1–2, 2010.

[8] N. S. A. Zulkifli, F. K. C. Harun, and N. S. Azahar, "XBee Wireless Sensor Networks for Heart Rate Monitoring in Sport Training," no. in C.

[9] R. In, "M2M : From Mobile to Embedded Internet," no. April, pp. 36–43, 2011.

[10] E. N. Barnhart and C. a. Bokath, "Considerations for Machine-to-Machine communications architecture and security standardization," 2011 IEEE 5th Int. Conf. Internet Multimed. Syst. Archit. Appl., pp. 1–6, Dec. 2011.

[11] Y. Chen, "S7-1 Challenges and Opportunities of Internet of Things S7-1," pp. 383–388, 2012.

[12] G. K. Thiruvathukal and M. Parashar, "Cloud Computing [Guest editorial]," Comput. Sci. Eng., vol. 15, no. 4, pp. 8–9, Jul. 2013.

[13] A. Alamri, W. S. Ansari, M. M. Hassan, M. S. Hossain, A. Alelaiwi, and M. A. Hossain, "A Survey on Sensor-Cloud: Architecture, Applications, and Approaches," Int. J. Distrib. Sens. Networks, vol. 2013, pp. 1–18, 2013.

[14] G. Anthes, "Invasion of the mobile apps," Commun. ACM, vol. 54, no. 9, p. 16, Sep. 2011.

[15] W. COLDWELL, "The 10 Best iPhone and Android cycle apps - Features - Gadgets & Tech - The Independent," 2013. [Online]. Available: http://www.independent.co.uk/life-style/gadgets-and-tech/features/the-10-best-iphone-and-android-cycle-apps-8567728.html. [Accessed: 26-Jan-2014].

[16] "Pololu - MinIMU-9 v3 Gyro, Accelerometer, and Compass (L3GD20H and LSM303D Carrier)." [Online]. Available: http://www.pololu.com/product/2468/resources. [Accessed: 02-Jun-2014].

[17] Atmel, "ATmega328P," 2014. [Online]. Available: http://www.atmel.com/devices/atmega328p.aspx?tab=overview. [Accessed: 16-May-2014].

[18] Texas Instruments Incorporated, "AM3358 | AM335x Processors | ARM Cortex-A8 Core | Description & parametrics." [Online]. Available: http://www.ti.com/product/am3358. [Accessed: 28-May-2014].

[19] Tekscan, "FlexiForce® Force Sensors | Single Button Force Sensing Resistor | Tekscan." [Online]. Available: http://www.tekscan.com/flexible-force-sensors#third. [Accessed: 23-Apr-2014].

[20] Digi International Inc., "XBee® 802.15.4 - Digi International." [Online]. Available: http://www.digi.com/products/wireless-wired-embedded-solutions/zigbee-rf-modules/point-multipoint-rfmodules/xbee-series1-module. [Accessed: 28-May-2014].

[21] Ed Callaway, "Low Power Consumption Features of the IEEE 802.15.4/ZigBee LR-WPAN Standard," 2003. [Online]. Available: http://sensys.acm.org/2003/sensys03-callaway.pdf. [Accessed: 10-May-2014].

[22] "Tekscan® A201-100 - Advantic System." [Online]. Available: http://www.advanticsys.com/wiki/index.php?title=Tekscan®_A201-100. [Accessed: 29-May-2014].

[23] "Google Maps Android API v2 — Google Developers." [Online]. Available: https://developers.google.com/maps/documentation/android/?hl=fr-FR. [Accessed: 26-May-2014].

[24] "YouTube Android Player API - YouTube — Google Developers." [Online]. Available: https://developers.google.com/youtube/android/player/. [Accessed: 26-May-2014].

Appendix B

Poster

WSN and M2M for Cycling Performance Assessment

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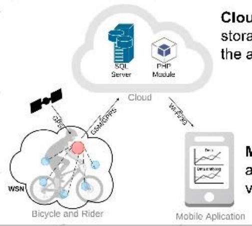
Abstract **- Cycling assessment to increase performance during sport training. In this condition the article presents a wireless sensor network including multi-sensing channels for dynamic and cinematic measurement during cycling training. The Smart Mountain Bike is a system that include the bicycle and the associated sports equipment, such as gloves, shoes and chest strap. The system is characterized by sensing channels as part of wireless sensor network which base station is expressed by embedded computer and a 3G/UMTS shield which permit the data communication with a cloud server. The data stored on the server is accessed through a mobile application that analyzes and correlates all user information and allows data visualization with a friendly graphical interface.**

System Overview

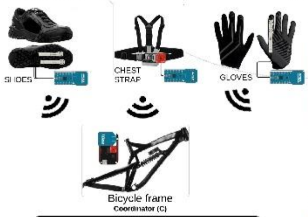


Cloud - server with a SQL database to ensure the storage of all information collected and to perform the advanced signal processing of the data.

Bicycle and Rider - consists of WSN where sensors are placed on sports equipment such as gloves, shoes, chest strap and bicycle frame.

Mobile Application - developed for Android OS that analyzes and correlates all user information and allows data visualization through a friendly graphical user interface.

Hardware



- Force Sensor - FlexiForce©
- Inertial Measurement Unit
- Microcontroller - ATmega328p
- Xbee S1
- Embedded computer

The **force sensor** is materialized by a flexible piezoresistor included in a voltage divider implementation. These sensors are used in gloves and shoes to measure the force applied to the brakes and pedals respectively.

IMU, is an electronic device that measures and reports velocity, orientation, and gravitational forces, using a combination of accelerometers, gyroscopes and magnetometer. These sensors are attached to the chest strap and measure the upper body motion. Attached to the bicycle frame it permit to monitor bicycle oscillations on the three plans of motion

The ATmega328P is a high-performance Atmel picoPower 8-bit AVR RISC-based microcontroller. Each **microcontroller** is responsible for the acquisition of sensor data, primary processing and communication of data to the network coordinator.

The communication between the WSN nodes is done through a network Zig Bee, for that we have an **XBee**® 802.15.4 module coupled to each microcontroller and to the embedded computer.

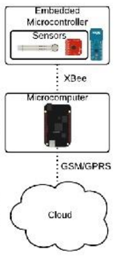
The central network node located in the bicycle frame it is materialized by an **embedded computer** Beaglebone Black with GPS/GPRS Cape that adds GPS and GSM/GPRS capabilities to the BeagleBone for tracking and M2M communication.

Software

The **embedded microcontroller** is programmed using C compiler language and several Arduino libraries. After primary processing the data is sent to the central node of the WSN.

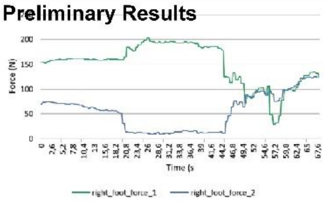
The **microcomputer** runs an Angstrom Linux OS and is programmed using node.js and bonescript library. This module gathers information from the IMU, GPS module and all other nodes in WSN, and establishes communication to cloud.

The **Cloud** has SQL server with database to store data and a module for PHP functions that allow read and write to the database using HTTP requests.



The **mobile application** was developed to Android OS and allows the user, trainer or athlete to log in and see the list of training sessions. The user can see all the information collected by sensors, tracking and add a video of the training session.

Preliminary Results



The prototype is still being assembled but we have collected some exemplar data.
Exploratory data collection was performed using force sensors in right foot and right hand.

Conclusions and future work

In the paper the general architecture hardware and software of smart mountain bike prototype is presented including elements of WSN for force, direction acceleration measurement during the training session. As well as a first version of a database and the mobile application.

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Appendix C

Patent

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Nº	CÓDIGO	DATA E HORA DE RECEÇÃO	MODALIDADE	PROCESSO RELACIONADO
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PAGAMENTO CONFIRMADO

PEDIDO DE PATENTE, MODELO DE UTILIDADE OU
DE TOPOGRAFIA DE PRODUTOS SEMICONDUTORES

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2 MODALIDADE / TIPO DE PEDIDO

Modalidade: PEDIDO PROVISÓRIO DE PATENTE
Realização de pesquisa pelo INPI: NÃO

3 EPÍGRAFE OU TÍTULO

REDE DE SENSORES EMBUTIDOS OU ACOPLADOS PARA MEDIR A INTERACÇÃO ENTRE O PRATICANTE E VEÍCULOS OU EQUIPAMENTOS DESPORTIVOS DE DESLIZE

4 RESUMO

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5	**FIGURAS**

6	**INVENTORES**

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7	**REIVINDICAÇÃO DE PRIORIDADE**

8	**DOCUMENTOS ANEXOS**

DOCUMENTO DO PEDIDO PROVISÓRIO DE PATENTE (Patente_ISCTE_IUL_OctavianPostolache_vf1.pdf)

9	**OBSERVAÇÕES**

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