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Data acquisition system on an off-road vehicleby a programmable logic device

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Abstract: *The following text shows the information to the proposal of a data acquisition system for a BAJA off road vehicle. This system pretends to measure suspension, steering and brake parameters, for example, the traveling of shocks in suspension, RPM's in each wheel, acceleration, deceleration of the vehicle. Using optic sensors, magnetic sensors and accelerometers plugged to a FPGA Nexys 2 board which programs is concurrent.*
Keywords: *Off-road vehicle, FPGA, data acquisition, sensor, accelerometer.*

I. Introduction

SAE International is a global association of more than 128,000 engineers and related technical experts in the aerospace, automotive and commercial-vehicle industries. SAE International's core competencies are life-long learning and voluntary consensus standards development. SAE International's charitable arm is the SAE Foundation, which supports many programs, including A World In Motion® and the Collegiate Design Series[1].The faculty of Mechatronics in UPIITA of INSTITUTO POLITÉCNICO NACIONAL in México, has a SAE Baja student chapter that belong to Collegiate Design Series. They have to designing and manufacturing a car prototype Off-Road type which uses an internal combustion engine of 10hp, has an approximate height of 1.55 m, length 2.13 m and width of 1.50 m, and can be operated a pilot of 1.70 m in height. It has an independent suspension and brakes, mechanical steering and rear-wheel drive (Fig. 1).This vehicle will be used for its versatility, safety and ability to match the behavior of a standard-size car. It will also provide important information to designers in order to improve vehicle performance.a system data acquisition has been implemented. This system consists of:

***A. Data acquisition system*. -**The system records signals from sensors, measuring physical variables in an instant of time and then the data are stored in a memory. You can obtain the following vehicle characteristics:1) Efficiency and Performance: The development of the vehicle on the track; the speed ratio of the gearbox, the efficiency of an engine or bending of the supports of a suspension; 2) Pilot Activity: related to the movements of the driver and its position on the path, the forces applied to the steering wheel, the pressure exerted on the seat or position of the accelerator and brake pedal; 3) Dynamic: chassis relative changes as the speed, tilt, longitudinal and lateral acceleration.

This is a single seater Off-Road prototype vehicle which uses an internal combustion engine of 10hp, it has an approximate height of 1.55 m, length 2.13 m and width of 1.50 m, and can be operated by a pilot of a height of 1.70 m. It has an independent suspension and brakes, mechanical steering and rear-wheel drive (Fig. 1).

Figure 1. Side view of vehicle

This vehicle will be used because of its versatility, safety and ability to match the behavior of a standard-size car. It will also provide important information for designers for a subsequent redesign.

B. Data to obtain. -We pretended to obtain the travel of each shock absorber, the acceleration of the axes (X, Y, Z) and the rpm of each tire.The results allow us to obtain the overall speed and the difference between each tire in a turn. The lateral, longitudinal and normal acceleration when the vehicle is subjected to a turn, jump or braking. And the displacement of the suspension to determine the correct setting of the shocks.

C. acquisition board. -The system has a data processing unit, which is responsible for receiving the signal from each of the sensors, processing, adding an identifier, store them in a memory, send them via a serial port and display them in a graphical interface.Due to the large number of tasks to be undertaken by the card, you must have a concurrent programming and, therefore, can do several tasks simultaneously without losing speed or data is why the processing unit data was chosen Spartan-3ENexys 2 FPGA [5] card that uses a VHDL language and was programed in Xilinx ISE Design Tools Design 14.4.

II. System Developed

The system is divided by each variable to be measured, and the processes of writing and reading data. The results of the tests on the vehicle are shown at the end.

Revolutions Per Minute. - This system has the ability to count the number of spins the front and rear wheels given in a minute. The analog signal is conditioned by square waves and is read by the board. With the maximum speed of Baja (60 km / h) and the diameter of the tires (23 in) the highest number of revolutions per minute required this corresponds approximately to an angular velocity of 545 rpm. For RPM measurement, we considered using a vehicle speed sensor (VSS) in their three types: optical, magnetic and variable reluctance or Hall Effect. Using this sensor is specifically for calculating the speed of the wheels, and is conditioned to the environment in which we will use.Considering the characteristics of all the sensors, the magnetic VSS was chosen, because of its easy acquisition, price and robustness for land. The sensor output is an analog signal with a value of 400 mVpp (Fig. 2), therefore an increase was required, configuration using an operational amplifier as adder and inverter subsequently a follower to maintain a constant voltage (Fig. 3).

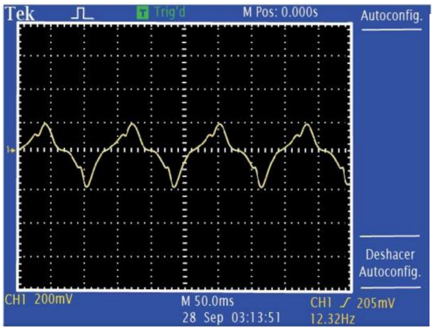


Fig. 2VSS signal image, view from oscilloscope**.**

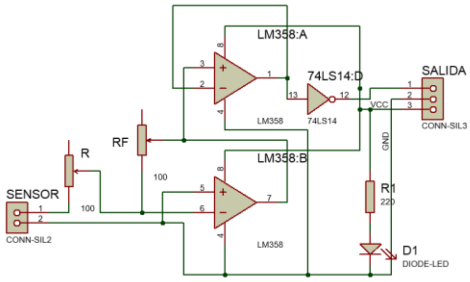
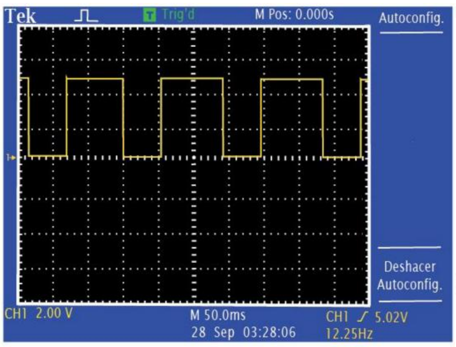


Fig. 3 Circuit for signal processing

The advantage gained by using a power amplifier whose reference is 5V and GND allowed us to eliminate a portion of the signal to increase the gain with a potentiometer, acquiring only the voltage change at the zero crossing. Finally add the hysteresis comparator with Schmitt trigger to remove noise and get a quadrature output (Fig. 4).

To attach the sensor in the front axle, we use the brake disk in each Wheel as a holed steel surface and the fix elements in the suspension and steering as a base of the fixing. The base which fix the sensor is made of steel and it is welded to the steering knuckle (Fig. 5).For the rear axle we chose to design a sample hub which is located in the output axle of the gearbox because the rear brake disk has no slots, just drills of 3/16”, and that it is not enough for the measurement.The board gets a square signal from the movement of the brake disk and it is measured/counted by the times of a upside appears in 1s, then the conversion is made in minutes.



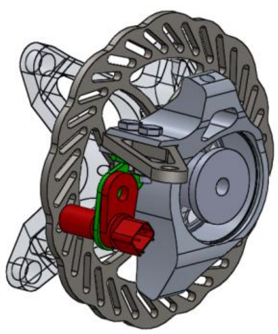


Fig. 4VSS processing signal image, oscilloscope view. **Fig. 5**VSS fitting in the front suspension system.

Shocks displacements. - This system is capable of detecting the linear displacement of the shocks in the front and rear suspension at compression and extension, implementing the linear encoder (EM2) from DIGITAL [6], which its outputs of A, B channel and index are 0 and 5 volts. This is why it is not necessary a signal processing and can be plugged directly to the Nexys 2 board. The encoder was used with 127 points per inch strip made by the same manufacturer, with the purpose of measuring the displacements with a resolution of 0.2mm. The measurement of the shocks' displacements will be for the front and rear suspension of the vehicle, in total four shocks which works independently. The shock to measure is the pneumatic FOX Float (0-120 psi), with a length of 8 in.To get together the sensor and the shock and get the measurements, a base was designed and printed for fix the encoder and the strip, which allows free displacement of the shocks.

The objective of the base is keep the strip rigid (blue) on a commercial aluminum profile (red). The encoder is mounted on a ring (yellow) to the free part of the shock, and the other part of the profile is fixed by a ring (green) mounted in the static part of the shock (Fig. 6).

Fig. 6 Fix of the encoder in the FOX shock.

The program was made in VHDL in base of the channel A and B, it will detect the direction of the displacement of the encoder, and it will count the pulses produced by channel A to have the data of the whole displacement of the shock. It is necessary have a reference point, which measures the displacement, does not matter if is positive or negative. The reference point is when the yellow ring is the closest to the green one. The maximum displacement of the encoder is 130mm, for that reason the offset was programed with this value. The schematic of this component in the VHDL program can be seen in Fig. 7.

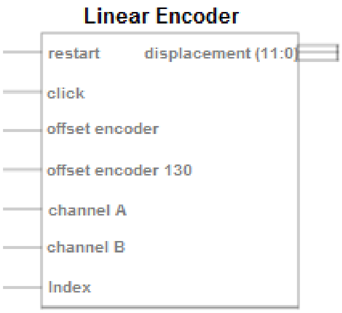
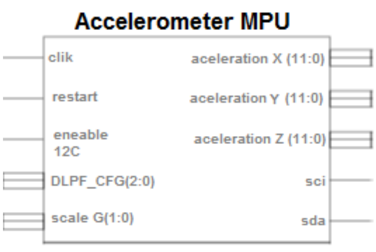


Fig. 7 Component of the program for the linear encoder. **Fig. 8** Accelerometer location in the vehicle (red points).

Acceleration XYZ. -We observed three important events: side acceleration, longitudinal acceleration, and deceleration or braking. In the automotive industry, this data gives substantial information about performance of the vehicle.This system gets the peak values of acceleration in the three axles (X, Y and Z) in the different environments where the vehicle performs. Using an accelerometer MPU-6050, which inside has a programmable low pass filter, which has a maximum frequency of 5Hz to reduce the noise produced by the engine vibration, furthermore has a programmable operation range of +/-2g, +/- 4g and +/- 16g and a protocol of communication I2C plugged to the sensor as a nigger and the board as a brain. For the lateral force experienced by the car at high speed, it is necessary to know the acceleration of CG. It also is searched to understand more closely the phenomena occurring on the wheel (neutral, sub steering and oversteering) for that reason a sensor was placed on each axle (Fig. 8). With three accelerometers on the perpendicular plane to the Y-axis, you can also see the acceleration and deceleration in the X-axis.

Since the MPU-6050 communicates via I2C at 400 kHz, and both low pass filter and the acceleration scale are configurable, a program that could set the accelerometer to any of its options was needed. The Fig. 9 shows the component of the program in VHDL capable of doing this task.



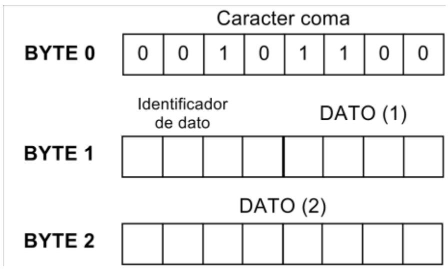


Fig. 9 Component of the program for the MPU-6050 accelerometer. **Fig. 10** Structure of data.

Where:
1) BYTE 0: The character ',' and indicates the beginning of a new data.
2) BYTE 1: Contains information identifier data type (acceleration, displacement or RPM) and part of the data value (most significant bits).

Identifier data type:
Acceleration: "0000" - "1000"
Offset: "1001" - "1100"
RPM: "1101" - "1111"
3) BYTE 2: Contains other data information value (least significant bit).

Thus, it has a maximum transmission speed of data is 3840.24 datum by second.However, it cannot be achieved, since communication errors occur, this due to delays that occur in the computer and change that occurs in the signal when using a USB-Serial Cable among others.Experimentally it was found that when the Nexys 2 is plugged directly to the computer, the maximum speed supported varies depending on the capabilities of the computer on which it is received, with 3000 data per second maximum average speed between computers tested.

The schematic diagram of the program in the Nexys 2 can be seen in the Fig. 11. In where the components are:
UART RX: Responsible for receiving the bytes sent from the computer through the RS 232 protocol to 115200 bauds.Instructions detector: This component detects whether the received bytes are a valid instruction, in which case changes the signals necessary to reprogram the NEXYS 2.

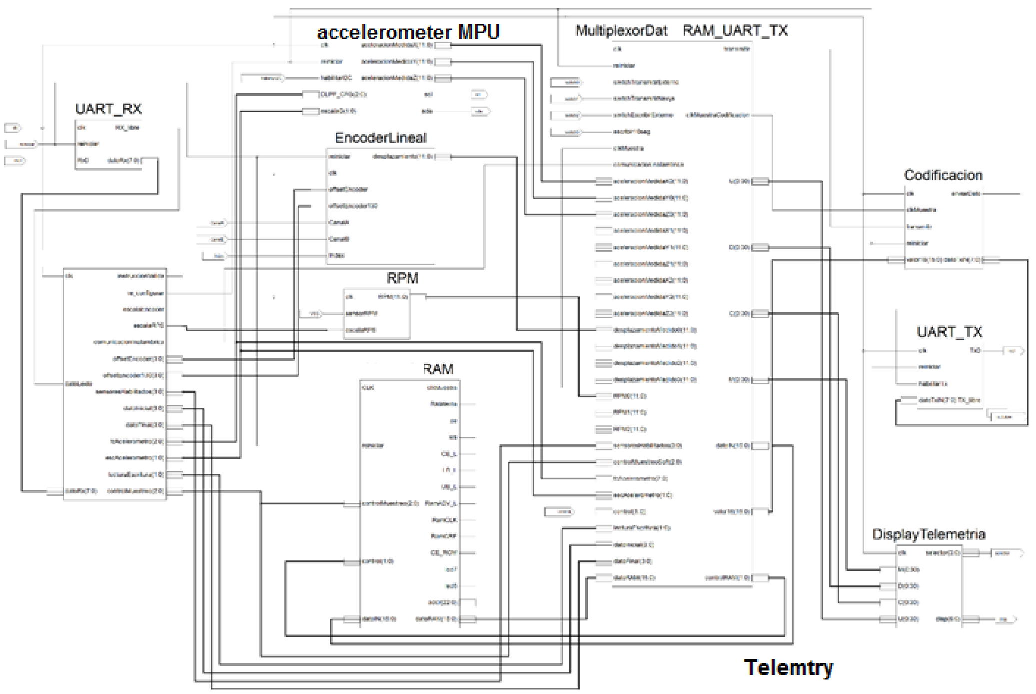


Fig. 10 Schematic of the program.

Valid instructions are as follows:
1) FS0. FS7: Modifies the sampling frequency for RAM from 100Hz to 4000Hz.
2) LE2, LE1 and LE0: Lee RAM, writes in RAM and none of the above respectively.
3) RA0 and RA1: Place the accelerometer signal reset to 0 and 1 respectively.
4) ES0 to ES3: Scales the accelerometer from 2g to 16g.
5) FC0 to FC7: Sets the cutoff frequency of the accelerometer from 270Hz up to 5Hz.
6) D 0 to D11: Set the sensors to be monitored.
7) O00 a O01 y F00 a F01: Stablishes the offset of every encoder to 0 and 130.
8) O10 a O11 y F10 a F11: Stablishes the offset to the encoder one to 0 and 130.
9) O20 a O21 y F20 a F21: Stablishes the offset to the encoder two to 0 and 130.
10) O30 a O31 y F30 a F31: Stablishes the offset to the encoder three to 0 and 130.

11) O40 a O41 y F40 a F41: Stablishes the offset to the encoder four to 0 and 130.
12) IN1 y IN0: Stablishes On/Off to wireless connection.

MPU Accelerometer: Configures the MPU module and acquires the acceleration data in every axis with a speed of 1000Hz each data.
RPM Meter: Monitors the VSS input and calculates RPM.
RAM: Writing and reading of each data in the RAM with a specified FS.
Multiplexor RAM UART RX: Receives all the data collected by the sensors and depending on the setup of the active sensors and the status of the wireless transmitter. Sends the sensed value to RAM and codification, this last one receives the clock signal needed to send the data to the UART TX.
Codification: Sends two byes of information that correspond to the sensed data and the character ",", to the UART TX component. It sends the Dato signal as well; this enables a character to be send via RS232.
UART TX: Transmits to the computer a single byte at a baud rate of 115200 symbols per second.
Display Telemetry: Shows the configuration of the sensors that are active, the read/write control of the RAM, the cutoff frequency and the scale of the accelerometer in the seven-segment displays.

Graphic Interface. - The data that is being sent by the processing unit, and is received by a computer and can be seen in a graphical interface (Fig. 12) that was made in LabVIEW™2014. The GUI allows the user to see the data that is being received by every measurement system and archive them for further analysis.

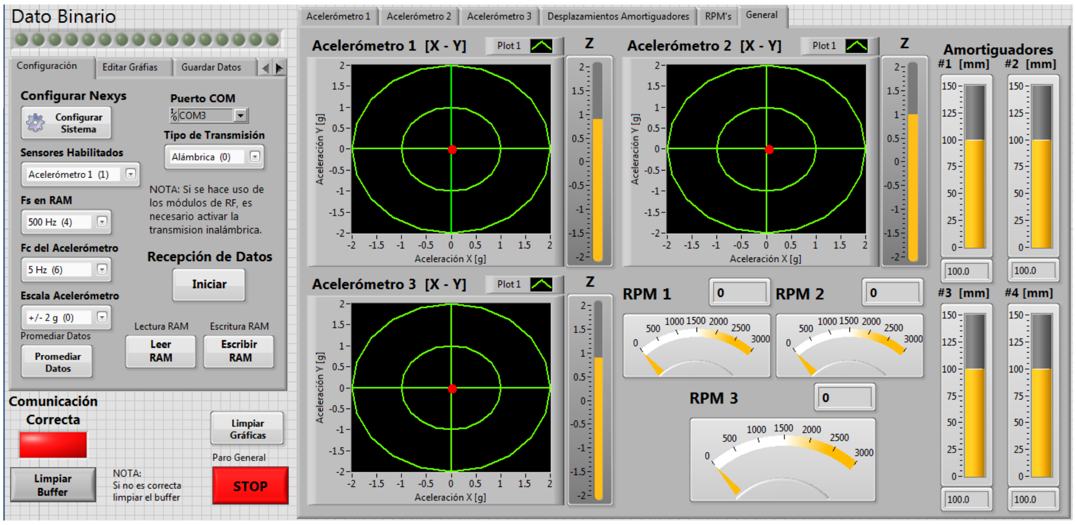


Fig. 12 Display of the graphical user interface's data, view in LabView.

III. ImplementationAnd Results

Once the measurement systems were implemented on the mechanical systems several tests were made under controlled scenarios, for the purpose of checking and analyzing certain aspects regarding the performance of the vehicle.

A. ***Total speed of the vehicle.*** -The test of maximum speed was done in an 80m circuit, with a 14° inclination and uneven terrain, with a pilot that weighted 70Kg. This test was used to check the engine performance and transmission graphs. After doing the test many times (Fig. 13) the maximum speed achieved was 49.21 km/h. The average acceleration was 4.393 m/s^2.

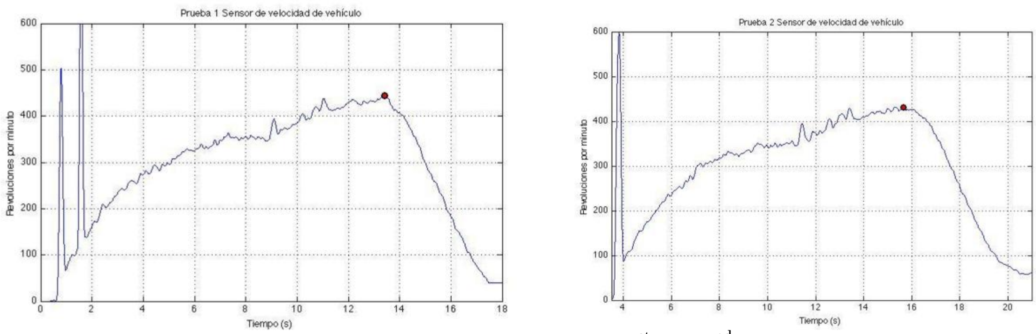


Fig. 13 Graph of RPM of 1st and 2nd test.

B. ***Restitution time after jumping.*** -This system was tested using a ramp that has a height of 0.7m. Each of the sensors that were attached to the shock absorbers had a sampling frequency of 1000Hz. The test shows that even when the suspension has the same shock absorbers their behavior is not the same (Fig. 14). There are many reasons behind this, for example the wear on the shock absorbers, the weight distribution on every wheel, variations in manufacturing, etc.

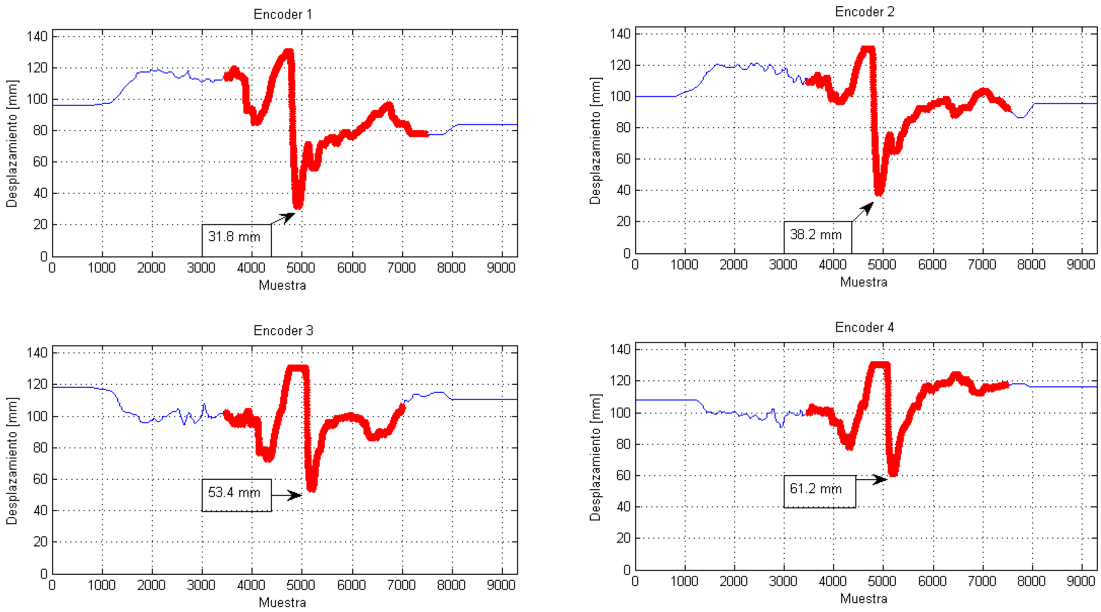


Fig. 14 Graph of displacement of the shock in each wheel.

The test showed that the frequency on which the front and rear suspension works is around 2.3Hz.

C. ***Impact after a jump and lateral force while turning.***-For the acceleration in a jump, we used the same ramp, which has a height of 0.7m, and the frequency rate was 1000Hz in each axis (X, Y, Z). The maximum peak of acceleration in the Z axis was 5.06g (Fig. 15).

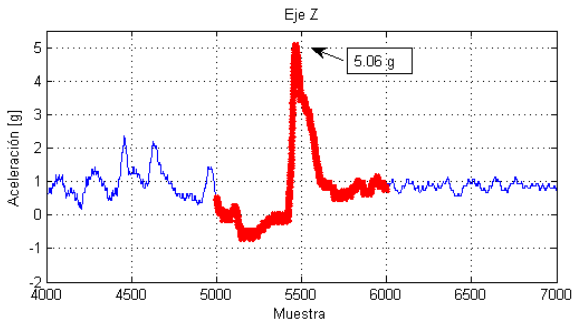


Fig. 15 Acceleration Z axis in a jump test

A second test was made in order to measure the lateral acceleration that the vehicle has while turning to the left. This test was done using a frequency of 333Hz in each acceleration axis. In the figures we can see the acceleration on the Y axis that accelerometers 1 and 2 measure (front and rear axis respectively). The variation between the front axis and the rear axis is an effect known as over steering [1], or better known as making the rear wheels slip (Fig. 16).

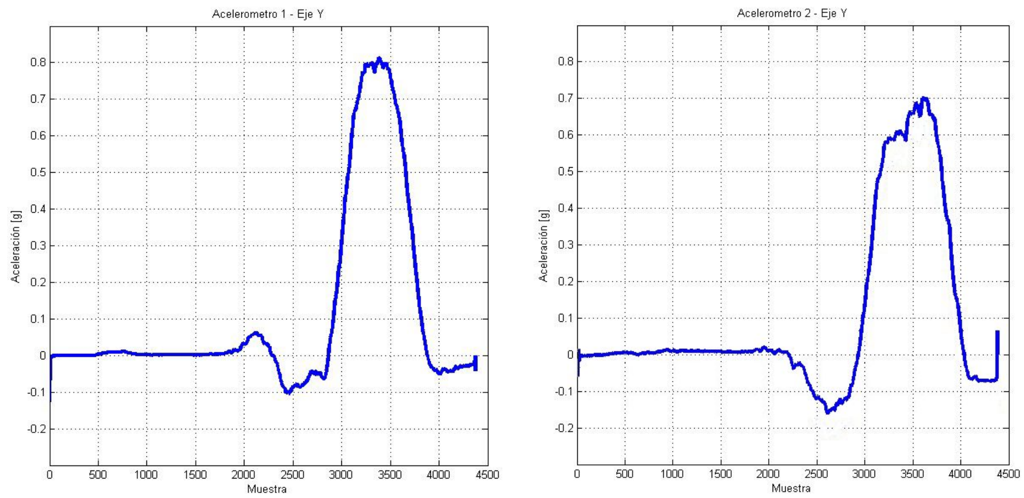


Fig. 16 Y-axis graph, showed by the 1 and 2 accelerometers, located in the front and rear axles.

IV. Conclusion

One of the biggest challenges faced was the implementation of the program in Nexys 2, as were several tasks that had to fulfill fortunately that can be scheduled concurrently facilitated independent programming, allowing to make the program for each task separately and then make the union of all. Therefore, it can be said that the selection of the board was a success. As a work of acquiring data had to be very careful with the handling of the times when each task is performed, from sampling, data processing, storage and transmission in order to have the components of synchronized program.

The use of accelerometers in all three points allowed to find significant differences in different tests. This sensor was presented more noise than the others, because this was affected by the vehicle's engine, however using its programmable low-pass filter and an average received data is obtained an acceptable signal.

An advantage that was found in the vehicle speed sensor is already conditioned to the automotive environment and give a signal output relatively easy to handle.

The encoder used are expensive, but with a very clean output signal, allowing you to analyze what happens in the suspension with much more detail.

At the end of the project it is expected that the data obtained from the sensors help perform analysis on more systems than proposed in this work. Eventually a method is developed to use the system remotely using radio frequency modules to not only save the data and analyze it later, but to view them while testing, and deploying more sensors and more detailed information.

Acknowledgements

We are grateful for the student chapter SAE-BAJA-UPIITA Institute for their support in building the prototype in which the telemetry system was implemented to describe their dynamic behavior.

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