A MONITORING SYSTEM TO ANALYSE THE INFORMATION GENERATED BY MEMS ACCELEROMETERS

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Abstract

In this paper a system for the analisis and acquisition of data produced by a MEMS accelerometer is presented. This system allows us to evaluate the responses of the device, whose knowledge has been applied to a specific case study for the analisys of foot movements.

I. INTRODUCTION

In several fields as the industry, biomedical and environment monitoring, both data acquisition and transmission to remote observatory for processing and visualization has become increasingly important. A lot of new devices are currently available on the market and their features need to be known in order to exploit their functionalities for new and attractive applications [1, 2].

From this comes the need for tools with low power, low cost, affordable and multi-functional characteristics that complement these features and can transmit them through wireless based technologies.

This paper deals with the problem of the acquisition of the acceleration provided by Micro-Electro-Mechanical Systems (MEMS) sensors and their transmission via wireless technologies, to remote units which use such information for the analysis of human movement. In particular, we will address the problem of measuring the distance traveled by a walking person, by analyzing the movements of the foot which is equipped with an accelerometer.

The use of wireless technology eliminates the need for wired connections between sensors and the data acquisition unit, this way facilitating the information acquisition of the moving objects. The accelerations detected by the sensor node of the mobile unit, is sent to a data acquisition system, which takes care of data, allowing the user displaying them in real time, and a subsequent filtering and saving.

The paper will be organized as follows: In Sect. 2 the MEMS accelerometer is introduced and the Hw data acquisition system is explained. In Sect. 3 the software data acquisition environment is presented and some graphic interfaces are shown which allow to analyze the signal produced by the accelerometer. In Sect. 3 a case study is presented, and finally in Sect. 4 some conclusions are provided.

II. SYSTEM COMPONENTS

The LIS302DL Accelerometer

The main component to consider is the LIS302DL accelerometer produced by STM which is shown in fig. 1. This is a three-axis linear capacitive accelerometer, ultra-compact, low-power, based on MEMS technology.

A MEMS is the integration of mechanical elements, sensors, actuators, and electronics on a common silicon substrate through microfabrication technology. These micro-mechanical components are fabricated using compatible "micromachining" processes that selectively etch away parts of the silicon wafer or add new structural layers to form the mechanical and electromechanical devices.

In the case of the accelerometer, the detection of the acceleration takes place through the change in capacitance of a capacitor to vary the distance between its plates. The device has integrated inside it, in addition to the components which are necessary for detecting the acceleration, some electronic circuits which provide a communication channel through a SPI/I^2C serial interface. This way, the acceleration measured by the sensor can be tranferred to external devices and can be processed.

The main features of the device are:

- three axes
- digital interfaces SPI / I^2C
- 2 outputs programmable interrupt
- supply voltage from 2.16V to 3.6V
- temperature range -40°C to +85°C
- ± 2g / ± 8g selectable

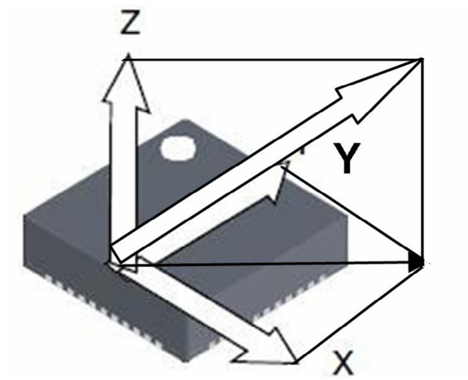

Fig. 1: Components of the acceleration along the 3 axes

The use of this device requires first a detailed study of its behavior, so it is possible to correlate the measured values with specific movements. This is essential to be able to use the accelerometer for the measuring the distance traveled. In order to capture them and analyze the data produced by the accelerometer, it was necessary to implement a suitable hardware architecture consists of several components in order to transfer the acquired values to the form processing and visualization.

IEEE 802.15.4 Protocol

An essential part of the architecture consists of two XBee modules [4] which are based on IEEE 802.15.4 standard protocol and are characterized by a low energy consumption.

The IEEE 802.15.4 defines the physical layer and the control mechanism for accessing the physical medium of the network model, providing communication in the ISM bands from 868 to 915 MHz and 2.4 GHz with a data rate up to 250 kb/s. In order to implement a communication system for the remote acquisition of the data provided by the accelerometer, the system shown in fig. 2 was implemented. In order to integrate the data provided by the accelerometer with the communication functionalities provided by the Xbee board, the two devices were integrated on a special Multi Interface Board.

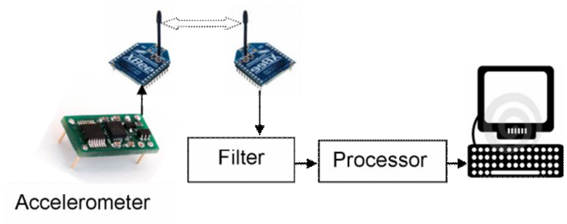

Fig.2: architecture of the remote data acquisition system.

MuIn – Multi Interface Board

The MuIn [3] is a versatile multi interface board, equipped with a PIC18F2520 microcontroller. The software environment which isavailable for this devise consists of a preloaded Bootloader which allows both to program the microcontroller through a serial port and to upgrade the firmware. The MuIn is a versatile device which can be used for many different applications. It can drive two H-bridges through the two channels and two PWM outputs. Moreover, it can read up to 5 analog devices as temperature sensors, analog sensors, potentiometers with a resolution of 10Bit per channel. In addition an I^2C bus can be used to control several devices, by sending commands via the serial connection. An important feature of this board is the presence of suitable connectors which allow to install an XBee module to create a ZigBee network.

III. DATA ACQUISITION SYSTEM

The data acquisition system has been implemented using the LabView [5] programming language. This is an object-oriented graphical programming environment, which allows to implement programs in the form of block diagrams, still retaining many features typical of the traditional programming environments.

The programming environment allows the user to build programs which are called virtual instruments (Virtual Instrument, VI) and are featured by a suitable user friendly interface which strongly simplifies the use of the instrument.

This programming environment is suitable for applications oriented to:

– data acquisition and management of electronic instruments;

– analysis and signal processing.

The advantages of LabView with respect to a traditional programming environment can be resumed as:

– easy to learn thanks to the use of function block programming, which is visual and intuitive;

– allows the code to be organized with a modular structure that allows complex programs to be split into simplest subprograms which can be reused;

– allows to collect the VI in libraries, so that sub-VI can be used by other VI, added to the source code by the programmer;

– provides a set of libraries for developing applications.

Functions of the data acquisition system

The system has been designed in order to o detect individually the three accelerations. Each sample acceleration is also processed, making these values in binary 2's complement.

The system, allows to store in a file the values of acceleration and other information related to the samples collected. These information can be used for specific applications and can be filtered so to eliminate any noise found on the samples.

Through this instrument it was possible to analyze the behavior of the accelerometer and investigate the relationship between the movements made and the results obtained.

The instrument which has been assembled is shown in fig.3.

A front panel present two different windows which can be used for displaying two different signals. For example it is possible to show the original acceleration provided by the accelerometer, and the signal after some type of filtering which allow to reduce the noise.

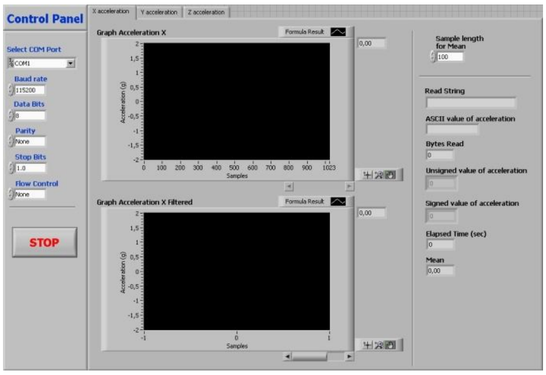

Fig. 3: Front Panel of the acquisition system

Acceleration data acquisition

The test can be divided into two phases: in the first phase, the accelerometer is stationary and it is inverted to evaluate the values measured on the Z-axis of the device.

The device is then moved back and forth and displays the signals obtained. We will see the effects of this test on the acquisitions taken individually by each of the three axes, to understand the characteristics of using a tool like the LIS302DL on mobile devices.

First stage

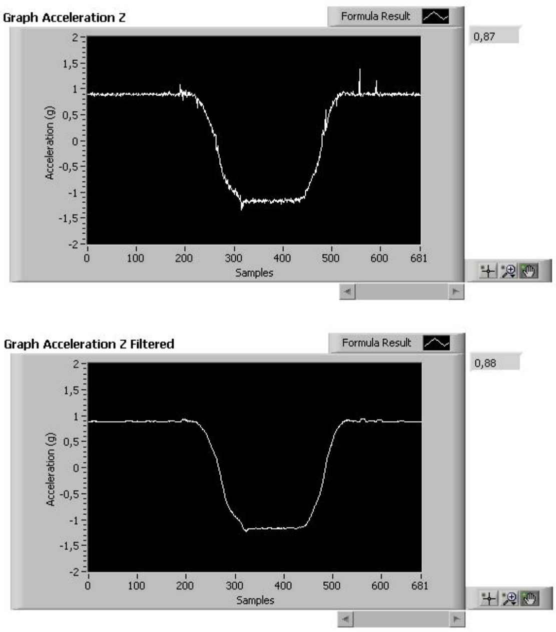

Fig. 4. Z axis accelerations in the first phase of the test

The two screenshots shown in fig.4 refer to the first testing phase of the prototype and relate to the Z axis. The first graph shows the acceleration obtained turning over the accelerometer, while the second graph shows the same acceleration, but after making the filtering operation.

It is possible to see that the value of the acceleration is equal to about 1g, when the device is in its starting position and that the values taken become equal to-1g, when the device is inverted, because this movement changes the orientation of ' Z axis. The graphs allow a comparison of values before and after filtering, highlighting the possibility of eliminating any disturbances present, due to vibration or other external sources. The filtering is done with a window size of 10 samples which has shown to provide the best results.

Second Stage

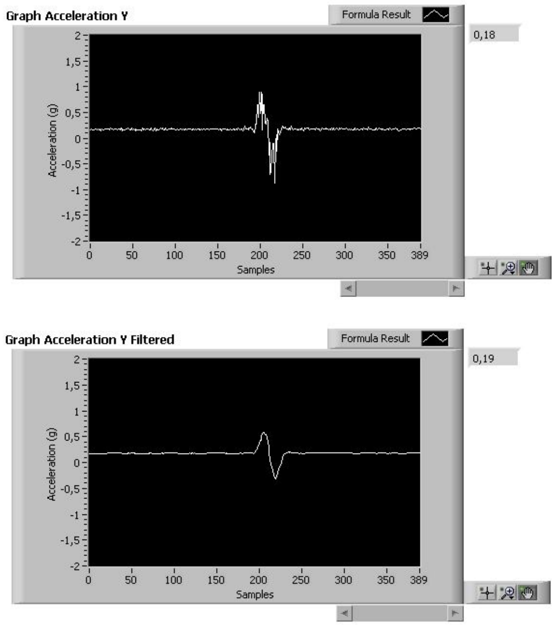

Fig. 5: Y axis accelerations in the second phase of the test

The other graphs concern the second phase of the test. For each test set, the first graph shows the measured value of the acceleration obtained after a forward and back movement. The second graph shows the same acceleration, but after the filtering. We can see how in the graphs, the acceleration is equal to about 0g initially, as the accelerometer is stationary; when it is moved forward and then stopped, the samples stored by the acquisition system show positive and negative values. The two graphs also allow a comparison between the values recorded before and after filtering. In this case too, the filtering is done with a size of 10 for the sample set, and we can see that the values obtained are not affected by the values related to noise sources.

The next figures show the graphs inherent, the accelerations recorded on the axes X and Z.

The graphs highlight the problems caused by vibration of the device, but thanks to the filtering operation the effect of the noise is gratly reduced.

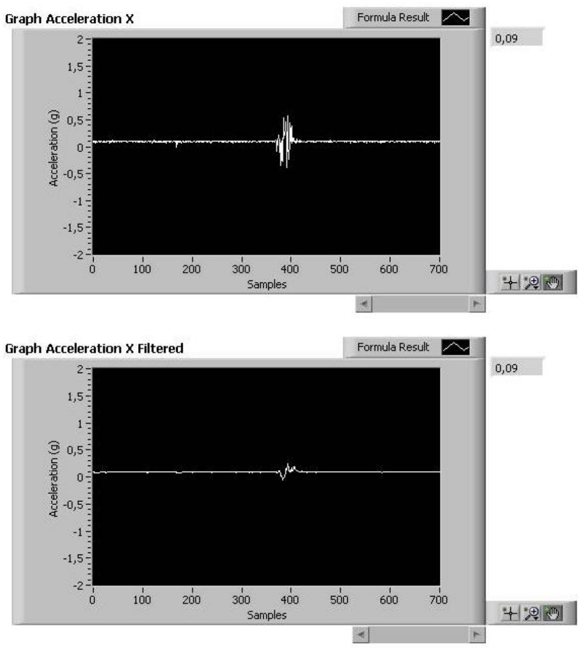

Fig. 6: X axis accelerations in the second phase of the test

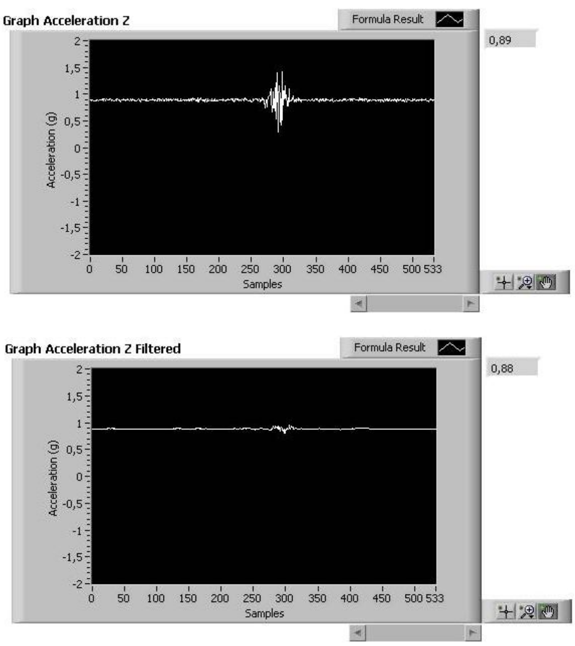

Fig. 7: Z axis accelerations in the second phase of the test

IV. CASE STUDY: MEASUREMENT OF WALKING DISTANCE

In order to measure the distance traveled by a moving person, the accelerometer was placed at the top of the foot, as shown in fig. 8:

When the foot begins to move, the accelerometer is subjected to forces along three axes: x, y and z. The fact that the shift does not occur along a horizontal plane makes it difficult to measure the movements the foot has made. In fact, the foot assumes an inclination which should be measured by a gyroscope in order to correctly calculate the projections of the displacements on the cartesian plane. In this way, through the acceleration, determined by the MEMS tilt of the foot (determined by the gyroscope) we could calculate precisely the speed and the distance made by foot.

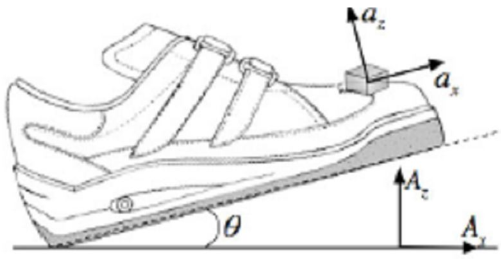

Fig. 8: Location of the accelerometer on the shoe

The approach used in this paper is instead based only on the use of the accelerometer, so that some assumptions regarding the inclination of the foot must be done. In fact, for recognizing the position of the foot, that is the angle the foot forms with the orizontal plane, we considered that each step is performed through 4 stages. For each phase the tilt of the foot is calculated using only the data provided by the accelerometer. Then these values are considered to be constant for the entire operation of the program.

Methodology for calculating the distance

To determine the distance, initially we refer to a training phase during which the initial inclination of the foot for each phase will be calculated.

We consider 4 stages:

- Resting phase (0), when the foot is in sleep state;
- Phase 1, the foot is starting up;
- Phase 2, the foot is in fully extended;
- Phase 3, the foot is going in the resting phase.

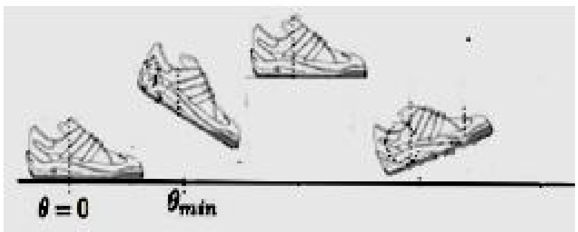

Fig. 9. The four phases considered for the calculation

Diring the training phase, the system must eliminate the gravitational component of the acceleration (the value is -9.8), in such a way to obtain, in the resting phase, a value which oscillate around the zero.

When the user goes through the training phase, the system collects data from the accelerometer, eliminating the component of gravity, and saves them in a temporary list. When the training is concluded, the values contained within the temporary list will be processed and will be averaged. The average value determined after the training will be used for the subsequent comparison with the value obtained during the walking phase, to determine what state the foot is found, with a reduced margin of error.

When the data acquisition process is started, the system has the need to recognize in which one of the four possible phases the foot is currently. So data provided by the accelerometer are still stored inside an array which is continuously processed in order to detect the associated state, and whenever it finds a particular sequence of states, it begins the procedure for calculating the speed and then the distance accomplished. Finally, the total distance will be calculated through the addition of all the partial values.

During the training, each measurement phase begins and ends when the foot is in the resting state.

We measure the acceleration of the foot and estimate the distance at each step. Vertical and horizontal axis movement of the foot is considered about one second, while in the sleep state it is fixed.

The distance made by the foot can be calculated by a double integral of the horizontal acceleration:

$$l(t) = \iint A\ (t) \cdot dt$$,

where A is the horizontal acceleration calculated for each of the 4 stages of the foot movement.

V. RESULTS

To evaluate the effect of the algorithm, several tests were performed along known distances, comparing the calculated values with the actual ones. The values are given in table 1.

Table 1.
Comparison between the real and measured distances

DISTANCE Calculated	Error in m	Cumulative distance
1.14155169715501	0.141552 (14%)	1.141552
1.95928945482114	0.959289 (95%)	3.100841
0.537193957089641	0.462806 (46%)	3.638035
0.991386857955745	0.008613 (0.01%)	4.629422
0.427825355743828	0.572175 (57%)	5.057247
1.10136750241029	0.101368 (10%)	6.158615
0.853463270916516	0.146537 (14%)	7.012078

The tests refer to a distance of one meter (approximately) which has been repeated several times. After its execution, the algorithm produces a distance in which the error is also calculated as the difference between the actual distance and the measured one.

As we can see the individual results are affected by an imprecision that in some cases is remarkable. This is because movements in the individual inclinations of the foot in the 4 phases may be different from those obtained during the learning phas. It should however be noted that the errors produced in the individual steps are compensated in some way, so the overall result can be considered satisfactory.

VI. CONCLUSIONS

In this paper I have presented a system for the acquisition of the information provided by an accelerometer. The tool which has been implemented allowed to analyze the information provided by the accelerometer and the filtering of some noise.

Moreover, I have also presented a case study for the analysis of foot movement. The results obtained were satisfactory, although worthy of further study.

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